Contaminant Loading to the Lower Duwamish Waterway from Suspended Sediment in the Green River

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Cover photo: Footbridge over the Green River at 119th St. and 42nd Ave. S., Tukwila, Washington (sampling site).

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by
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Table of Contents

Page

List of Figures

List of Tables

Page

Abstract

The Lower Duwamish Waterway (LDW) is an approximately 5-mile long section of estuary in Seattle, Washington, that is undergoing remedial investigations and feasibility studies directed by state and federal authorities.

The sediment contaminants that pose the greatest risk to aquatic resources or human health in the LDW include polychlorinated biphenyls (PCB), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), arsenic, and carcinogenic polycyclic aromatic hydrocarbons (cPAH). Cleanup levels for these contaminants and choice of remedial actions will be influenced by future loads of sediment and contaminants predicted to enter the LDW.

The goals of this study were to measure concentrations of contaminants associated with suspended sediment in the Green River and use them to estimate contaminant loads to the LDW. Samples of suspended sediment were collected on 7 occasions during late 2008 and early 2009 that represented a wide range of conditions. Sampling was done by pumping river water into continuous-flow centrifuges and through stainless steel sieves. The sediments retained by these devices were analyzed for total suspended solids, total organic carbon, and the contaminants of greatest interest.

Contaminant concentrations associated with Green River suspended sediment were generally greater than those measured in surface sediments deposited upstream of the LDW and less than concentrations indicated by water samples collected as part of a separate monitoring program. Contaminant levels associated with sand-sized particles were usually lower than those associated with a finer size fraction.

Contaminant loading rates were calculated for each sampling event. Estimating annual contaminant loads was problematic because most sediment loading occurs during a few high-flow events and no suspended sediment samples were collected during the rising stage of such an event. Results were also used only to approximate lower- and upper-bound values for annual contaminant loads and instream concentrations. These values were sensitive to assumptions about the daily contaminant loading during the highest sediment load (high-flow) events.

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Introduction

Background

The setting, recent history, site description, problem statement, goals, and objectives for this study are summarized in the Quality Assurance Project Plan (Gries and Sloan, 2008). Some of the more relevant information is repeated below.

The Green and Duwamish River system drains a large watershed, mostly urbanized in its lower reaches. The river system empties into Elliott Bay near downtown Seattle, Washington. This report considers the Green River to begin upstream of the navigation turning basin located at approximately River Mile 4.8.[1]

Land uses within the Green/Duwamish watershed, together with common practices of industries, municipalities and individuals, have contributed to sediment contamination throughout much of the channelized sections of the Duwamish River. Within these sections, the Lower Duwamish Waterway (LDW) sediment cleanup site extends approximately 8 kilometers (5 miles) from the south end of Harbor Island to an undefined boundary above the upstream turning basin (Figure 1).

The Washington State Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) have identified the following sediment contaminants to be of greatest concern in the LDW:

- Polychlorinated biphenyls (PCBs).
- Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs).
- Carcinogenic polycyclic aromatic compounds (cPAHs).[2]
- Arsenic.

A draft remedial investigation report (LDWG, 2007) describes the distributions and levels of these and other contaminants found in the LDW sediments.

The choice of cleanup levels for the priority contaminants and the feasibility of various cleanup alternatives are now being discussed. They are both influenced by the predicted future loading of contaminants to the LDW associated with Green River suspended sediments. Estimates of contaminant loading are based on 2 things:

- Sediment load, as predicted by a sediment transport model (STM) prepared with the remedial investigation (LDWG, 2008).
- Contaminant levels assigned to incoming sediments.

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[1] This convention is intended to reduce confusion between the Lower Duwamish Waterway cleanup site and the Lower Duwamish River located immediately upstream. Common practice considers the Duwamish River to extend upstream to where the Black River enters the Green River (River Mile 11).

[2] The carcinogenic PAHs (cPAHs) are: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

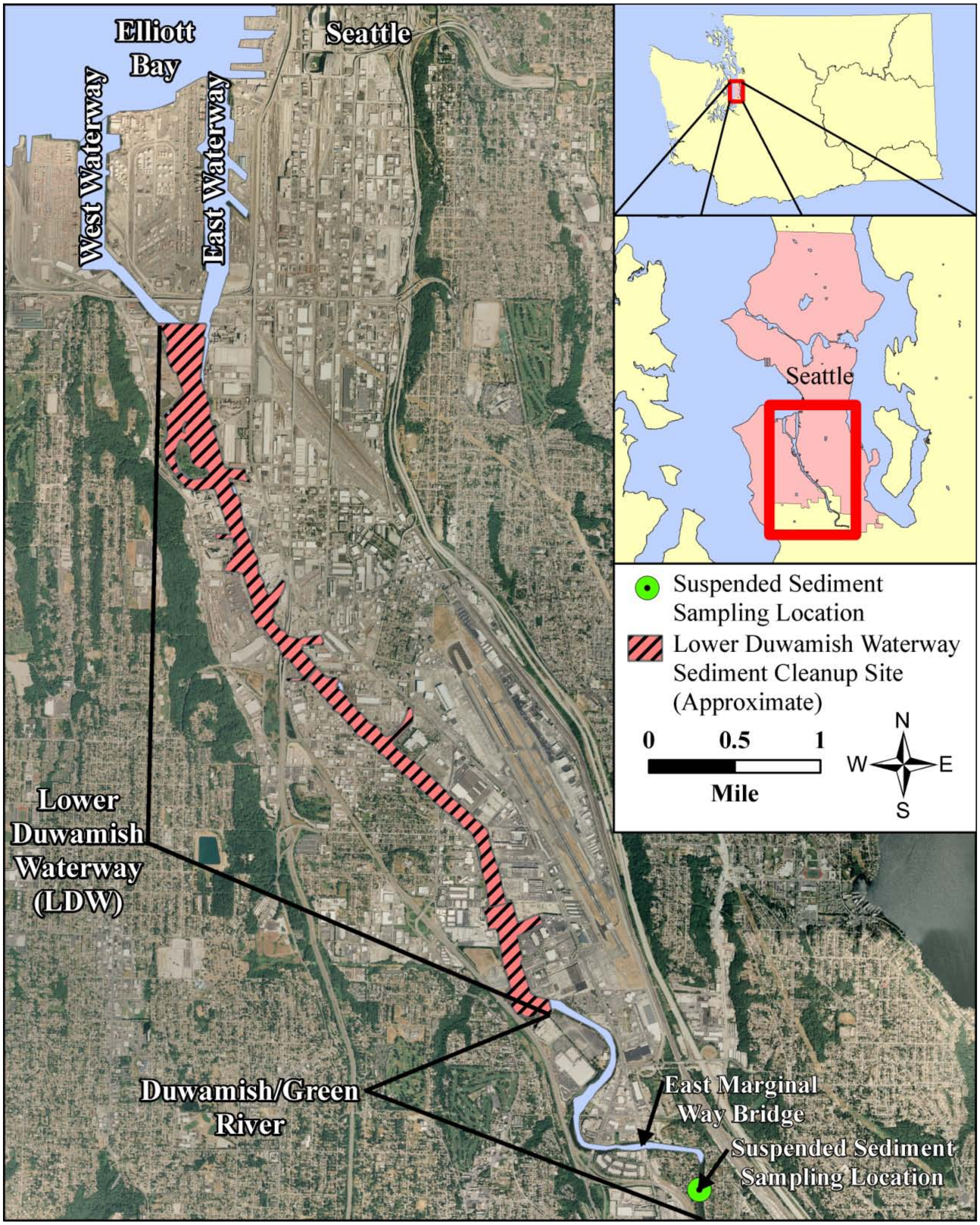

Figure 1. The Lower Duwamish Waterway sediment cleanup site and location where suspended sediment samples were collected from the Green River.

The West and East Waterways border Harbor Island. The southern (upstream) boundary of the cleanup site is approximate.

The STM predicts:

- Over 99% of the sediment load to the LDW comes from the Green River.
- 76% of the sediment load enters from the Green River as suspended sediments (157,000 metric tons (mT) per year).
- The remaining 24% of the sediment load is *bed load* from the Green River (50,000 mT/yr).
- About one-half of the total sediment load (nearly all of the bed load and approximately one-third of the suspended sediment load) accumulates within the LDW cleanup site.
- The remaining one-half of the total sediment load (two-thirds of the suspended sediment load) passes through the LDW.
- Nearly all of the suspended sediment passing through the site is comprised of fine-grained material (particles <63 µm in diameter) that originates in the Green River.

A draft Feasibility Study (LDWG, 2009) ascribes most contaminant loading to incoming sediments from the Green River, lateral sources, and resuspension of surface sediments within the waterway. Estimates of contaminant loads associated with suspended Green River sediments are based on the predicted sediment loads and concentrations of priority contaminants assigned to the loads. Lines of evidence for contaminant concentrations associated with incoming suspended sediments and bed load include results from the following data sets:

- Whole water samples collected upstream (Tukwila, Washington) and normalized to the suspended solids in each sample (King County, 2009).
- Surface sediments collected upstream of the LDW (LDWG, 2007; Longtine, 2009).
- Surface sediments collected in clean areas of Puget Sound (DMMP, 2009).
- Surface sediments collected from the Seattle area and Elliott Bay (LDWG, 2007).

Other studies have measured contaminants in suspended sediment (see *Results and Discussion*), but little is known about contaminants associated with suspended sediments in the Green or Duwamish Rivers. Less is known about concentrations associated with different size classes of suspended sediments. Such data gaps are the impetus for the present study.

Project Objectives

The objectives of the study were to:

- Measure levels of priority contaminants associated with suspended sediments collected from the Green River and use the results to estimate contaminant loading.
- Measure contaminant levels associated with different size classes of suspended sediments.

A companion study assessed short-term transport and accumulation patterns of suspended sediment within the LDW using artificial sediment as tracers (Gries and Sloan, 2009).

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Study design

The conceptual design was to measure contaminants associated with suspended sediment in the Green River over a wide range of in-stream flows and suspended solids concentrations.[3] Relationships between the contaminant results and other measured parameters, if any, could then be used to estimate contaminant loading.

Specific design elements included:

- Pumping river water into continuous-flow centrifuges to collect samples of suspended sediments in the Green River.
    - Centrifugation methods have been used in other Ecology studies of suspended particulate material (Seiders, 1990; Serdar, 1997a; Serdar, 1997b). Yake (1993) concluded that “analysis of centrifuged particulates from effluents and streams may provide the only practical way of quantifying particulate-bound pollutant loads of organic chemicals” and recommended using “the centrifuge system for … quantifying organic pollutant loads associated with the particulate fraction of rivers”.
    - Centrifugation methods have also been used successfully by other researchers (Kodes and Hypr, 2007; Rees et al., 1991; Ongley and Thomas, 1989; Horowitz et al., 1989).
- Pumping river water through stainless steel sieves to collect suspended sediment belonging to larger particle size classes (sands, >63 µm).
- Sampling over several seasons to capture a range of flows and suspended sediment concentrations.
- Measuring concentrations of total PCBs, PCDD/F, arsenic, and cPAHs associated with the samples.
- Combining suspended sediment concentration data with mean daily flows to estimate sediment loads.
- Calculating daily contaminant loads for each sampling event.
- Identifying relationships between concentrations of contaminants associated with suspended sediment and other measured parameters, if any, and using them to estimate annual contaminant loads.
- Presenting study results side-by-side with other lines of evidence for contaminant concentrations that may be expected to enter the LDW after cleanup actions are taken.

Measurements of river stage, water depth, current velocity, total flow, salinity, depth of pump intake, concentration and size of in-situ suspended particles, total suspended solids (TSS), total organic carbon (TOC), and dissolved organic carbon (DOC) were also made to guide sampling efforts and assess how well the samples represented suspended sediments present in the channel.

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[3] The study was not intended to assess bed load transport of near-bottom sediments in the Green River to the LDW.

Site selection

Several locations were considered for collecting samples of suspended sediment. The site finally chosen was a footbridge in Tukwila that crosses the Green River approximately 1.8 miles upstream of the LDW boundary (Figures B-1 and B-2). Reasons for this choice included:

- Suspended sediments at this location were likely to capture and represent nearly all of the upstream contaminant sources and not likely to be substantially influenced by contaminants from the LDW.
- The location (within a straight reach of the river) and channel geometry (low discharge outside of vertical bridge supports) promoted a well-mixed water column.
- The location provided good and safe access for sampling.

A disadvantage of the sampling site was that the river was known to still be influenced by tides (Stoner, 1967). Tides were observed to cause water levels to change as much as 10 feet (3 meters) over the course of a day. Strong flood tides were also observed to reverse the direction of flow for periods as long as approximately 6 hours. Therefore, current velocity, direction of flow, and the concentrations and characteristics of suspended sediments were expected to be variable. Because of this variability, suspended sediment samples were collected over 1-2 full tidal cycles (24-48 hours) to better represent mean daily conditions in the water column.

Methods

Field measurements

To help understand river hydrodynamics, guide sampling activities, and assess the representativeness of the suspended sediment samples, the following parameters were measured:

- Stage height (water levels) and channel depths.
- Current velocity and flow.
- Specific conductivity and salinity.
- Pump intake depths.

A staff gage, mounted on a bridge abutment (Figure B-2), was used to measure stage height. The gage was not calibrated to a vertical datum so values recorded were only relative. Relative stage height was recorded in conjunction with other field activities (measuring salinity profiles, adjusting pump intake depth, collecting suspended sediment from sieves). Water depth in the central channel was measured with a lead-weighted line marked at 1-foot intervals. Water depth was also recorded during measurements of current velocity and flow.

Ecology measured current velocities and flows at the Tukwila sampling site using an acoustic Doppler current profiler (ADCP; Teledyne RD instruments StreamPro) following procedures described by Shedd et al. (2008).[4] The measurements were made at approximately 3-hour intervals, corresponding to different tidal phases, during all sampling events except September and December. Field data were post-processed to estimate the mean current velocity within 1 vertical foot and 2 horizontal feet of the pump intake. Near-pump current velocities were compared to the mean velocity of the overall channel.

Mean daily flows used for loading calculations were predicted from automated readings at the USGS gaging station in Auburn and a rating curve that was developed for that site.[5] USGS staff verified the flow at this station monthly using standard methods (Glysson and Edwards, 1988).

Hydrolab multi-parameter instruments (Hach® Hydromet) were used to measure specific conductivity and salinity when saline water could potentially reach the sampling site. Salinity profiles were measured during and soon after flood tides when daily flows were less than 28 cms (1,000 cfs) (Stoner, 1967). Measurements were intentionally qualitative, so the instruments were only zeroed using de-ionized water prior to use.

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[4] Simultaneous measurements of Green River flow at the USGS station in Auburn on December 10, 2008, showed mean ADCP flow was 6% less than the flow measured by USGS staff.

[5] The Auburn gauging station is located upstream of tidal influences and so provides good data on baseflow. Additional flow from tributaries, surface runoff, and groundwater downstream of the Auburn station likely contribute <5% to the mean daily flow at the Tukwila sampling location (LDWG, 2008; King County, 2009).

The pump intake depth was monitored and periodically adjusted to a target of 0.6 times the mid-channel maximum depth (Rantz, 1982).[6] Depth adjustments were based on stage height, tidal phase, salinity, and the maximum water depth.

Concentrations and size distributions of in-situ suspended sediment were measured using a LISST-Streamside (LISST) laser diffraction instrument (Sequoia Scientific, Inc.).[7] The instrument was deployed near the pump conveying river water to the centrifuges. Background or blank samples of de-ionized water were first analyzed until performance was acceptable. The instrument was then set to operate in an automated sampling mode, with samples measured at intervals varying from 5-60 minutes. The LISST was also used to analyze water samples and map in-situ particles throughout the channel, but only on one occasion.

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[6] Pump depths were adjusted at least every 3 hours, and more frequently (< 1 hour) during large flood and ebb tides.

[7] The instrument measures the characteristics of laser light diffracted by suspended particles that pass by.

Sample collection

Suspended sediments

Timing

Samples of suspended sediments were collected approximately monthly between mid-July 2008 and late January 2009 (Table 1 and Table E-1). Timing of the 7 sampling events was based on:

- River flow.
- Predicted tides.
- Availability of field equipment and staff to assist with sampling.

River flow was an important factor determining the timing of sampling events. However, flow had to be tracked well in advance because recruiting field staff, preparing equipment, and mobilizing for sampling required a long lead time. Once at the sampling location, tides dictated the start and end time of all field sampling activities.

Table 1. Summary of centrifuge sampling events.

Event ID	Sampling Dates 2008-09	Sampling Duration (hours)
1	July 15-17	47
2	August 25-27	48
3	September 29-30	24
4	October 15-16	24
5	November 17-18	24
6	December 15-16	24
7	January 20-21	24

Continuous-flow centrifugation

Continuous-flow centrifuges were used to collect enough mass of suspended sediment from the water column to measure concentrations of the priority contaminants. Details of the methods, modified from Seiders (1990), are summarized here.

A Grundfos SP4 groundwater/well pump was attached to a bridge board cable and lowered from a mid-channel location (Figure B-3). Pump depth was maintained as close as possible to 0.6 times the maximum depth at that location. As much as 20 liters (5 - 6 gallons) per minute of river water was pumped through 65 meters (>210 feet) of Teflon-lined tubing to the east end of the footbridge (Figure B-3). Flow was split so that approximately 30% of the flow entered an Ecology trailer housing the 2 centrifuges (Alpha Laval, Sedisamp II, Model 101L) shown in

Figure B-4. It was not practical to maintain flow rates to the centrifuges proportional to changing river flows. Instead, an attempt was made during each sampling event to maintain a flow rate of 3 liters (0.8 gallons) of river water per minute to each centrifuge.

Flow to the centrifuges was regulated using:

- A ball valve in the influent tubing outside the centrifuge trailer.
- An on/off check valve inside the centrifuge trailer.
- 2 ball valves on a control panel (regulated flow to each individual centrifuge).
- 2 float gages on the same control panel measured instantaneous flow to each centrifuge.

Actual flow rate to the centrifuges was measured by periodically recording the time required to fill a calibrated container with centrifuge effluent.

After 24 or 48 hours, all pumping and centrifuging activities were stopped. Suspended sediment in the centrifuge bowls was processed in the field (Steps 1-5) and at Ecology (Steps 6-8):

1. Work surfaces in the trailer were cleaned and otherwise prepared.
2. Influent and effluent tubes were detached from the centrifuges.
3. Centrifuges were opened, using powderless Nitrile gloves, so as not to mix sediments with overlying water (bowl water).
4. Bowl water was removed from centrifuges using a 60-mL glass syringe (Figure B-5) and placed in 1-gallon pre-cleaned glass jars.
5. Sediment was removed from the centrifuge bowls (Figure B-5) using stainless steel spoons and spatulas, and placed in 8 - 16 oz pre-cleaned glass sample jars.
6. Sediment carefully removed from other centrifuge parts (disks and distributors) and sediment removed from bowl water by centrifugation (3000 rpm for 10 - 20 minutes) were combined with sediment already in jars.
7. Sediments were mixed with a stainless steel spoon until color and texture were homogeneous.
8. Total wet weight of the suspended sediment collected was recorded, and subsamples were distributed to 2 - 4 oz pre-cleaned glass jars for analysis.

Field sieving

Sieving suspended sediments has been shown not to substantially alter the concentrations of contaminants subsequently measured (Fisher et al., 2004). Therefore, the following field sieving method was developed.

The 70% of river water not pumped to the centrifuges was passed through nested stainless steel sieves enclosed in a 19-liter (5-gallon) plastic bucket to exclude fugitive dust. The suspended sediment samples collected at this “Sieve A” station were of two classes of sand-sized particles (63-250 µm and >250 µm). The sand-sized particles were rinsed off sieves every 15-60 minutes into pre-cleaned, appropriately labeled, 8-oz glass jars (Figure B-7). Rinsing was done using a

Nalgene squirt bottle filled with de-ionized water or pumped river water.[8] Each time the sieves were rinsed, the duration of the flow was recorded. Flow rates to the sieves were also measured periodically, using the same container and timing method as was used to measure flow to the centrifuges. The total volume of water producing each final sieved sediment sample was calculated from total duration of flow and the measured flow rates.

Two approaches were used to increase the limited sample mass available for analysis:

- Samples of the two size classes of sand-sized suspended sediment, collected separately, were sometimes combined.
- A second pump was deployed and a second "Sieve B" station was set up for the last 4 sampling events (Figure B-6 and B-7).

On most occasions, enough mass of was collected on the sieves to measured total PCBs and TOC. On some occasions, other priority contaminants could also be analyzed.

Water

Water samples were collected to assess some key water quality parameters (TSS, DOC, and TOC) and, more importantly, to assess representativeness and comparability of sampling methods:

- Results for time-integrated samples of centrifuged suspended sediment, collected by continuously pumping water for 24-48 hours, were compared to composited grab samples collected over the same timeframe.
- Results for composited water samples were compared to the average results for the discrete grab samples from which they were created.
- Efficiency of centrifuges at removing suspended sediments from the water column was tracked throughout the study.

To measure centrifuge efficiency, samples of pumped river water were collected directly from influent and effluent tubing at nearly the same times. The percent of suspended solids removed was calculated using TSS concentrations and the following equation:

$$\%\ \mathbf{Efficiency} = \mathbf{100\ x} \frac{(\mathbf{TSS_{influent}} - \mathbf{TSS_{effluent}})}{\mathbf{TSS_{influent}}}$$

To assess if pumping river water introduced bias into collection of suspended sediments relative to grab samples, water samples were also collected using a 1.5 liter Kemmerer bottle sampler (Joy, 2006). Grab samples were collected from as close to the pump intake as possible and at nearly the same time as centrifuge influent samples were collected. Weight added to the sampler minimized deviation from the vertical and consequent error measuring water depth.

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[8] River water was used because it was more practical and added negligible mass to what was already captured on the sieves.

Composite water samples were created from discrete samples collected approximately every 3 hours (to coincide with tidal phases). River water was transferred from the Kemmerer into stainless steel containers. Influent and effluent water was transferred directly from centrifuge tubing into separate stainless steel containers. After mixing, subsamples of each type of sample were collected using a 30-mL or 60-mL plastic syringe and placed in final sample containers appropriate for analysis of conventional parameters. Samples to be analyzed for DOC were filtered in the field through a disposable 0.45-µm pore-size filter into a small amount of hydrochloric acid. River, influent, and effluent samples were analyzed for TSS, TOC, and DOC. Discrete samples were also collected during 2 of the sampling events and analyzed separately.

Sample storage and handling

All samples of suspended sediment (centrifuged and sieved) were stored in pre-cleaned and certified glass jars. Water samples were stored in clean plastic containers. All containers were provided by Manchester Environmental Laboratory (MEL).

Water, centrifuged sediment, and sieved sediment samples were stored in coolers on ice while in the field and during transport to Ecology facilities. Water samples were transferred to MEL within 24-48 hours and held no more than a total of 7 days from collection before being analyzed. Centrifuged and sieved sediment samples were stored in the dark at -20^{o}C or sent directly to MEL after post-processing, unless noted otherwise. Freezing samples allowed transfer and analysis in batches. Standard chain-of-custody procedures were followed.

Decontamination

All appropriate items such as tubing, centrifuge parts, sieves, stainless steel containers and implements, and glass syringes were pre-cleaned as described in the Quality Assurance (QA) Project Plan (Gries and Sloan, 2008; Ecology, 2006). Key steps included:

- Liquinox detergent wash and tap water rinse.
- 10% nitric acid wash followed by 3 de-ionized water rinses.
- Acetone rinse and dry.
- Hexane rinse and dry.

Pumps, made almost entirely of stainless steel, were pre-cleaned by immersing and rinsing them in river water prior to sampling. Controls for the flow of influent river water to the centrifuges were cleaned with 100% methanol and de-ionized water because they would not tolerate all of the wash and rinse solutions listed above. Bottles, syringes, and filters were color coded to prevent cross-contamination between samples of different types.

Laboratory methods

Analytical methods used for this study are summarized in Table 2.

Table 2. Analytical methods used for study of contaminant loading to the Lower Duwamish Waterway.

Parameter	Lab	Matrix	Sample Preparation Method	Sample Cleanup Methods	Analytical (Instrumental) Method [a]
Total suspended solids (TSS)	MEL	Water	-	-	EPA 2540D
Total organic carbon (TOC)	MEL	Water	-	-	EPA 5310B
Dissolved organic carbon (DOC)	MEL	Water	-	-	EPA 5310B
Total solids Air dried solids	MEL	Sediment	-	-	PSEP (1986) Donegan (2004)
TOC	MEL	Sediment	-	-	PSEP (1986)
Total polychlorinated biphenyls (PCBs)	MEL	Sediment [b]	EPA 3545	EPA 3620 EPA 3665	EPA 8082
Polychlorinated dibenzodioxins/ dibenzofurans (PCDD/Fs)	PRL	Sediment [b]	EPA 1613B	EPA 1613B	EPA 1613B
Polycyclic aromatic hydrocarbons (PAHs)	MEL	Sediment [b]	EPA 3545	EPA 3630	EPA 8270 SIM
Arsenic	MEL	Sediment [b]	EPA 3050B	-	EPA 200.8

a = four-digit EPA methods taken from APHA (2005).
b = also field blanks (water).
MEL = Manchester Environmental Laboratory.
PRL = Pacific Rim Laboratories, Inc.

Sediment samples required drying prior to measuring contaminants. MEL transferred samples to pre-cleaned Pyrex Petri dishes, placed them in a vented air-drier box, and dried them for 3-4 days (Weakland, 2008; Donegan, 2004). The percent of air-dried solids in each sample was calculated from initial wet weight and final air-dried weight. The information was used to calculate and report contaminant levels on a dry-weight basis. It was also used to determine the % fines in the suspended sediments:

$$\textbf{\% Fines} = \mathbf{100 \times (TSS_{cent} - TSS_{sieve})/TSS_{cent}}$$

where
TSS_{cent} = air-dried mass of centrifuged sediment/liters pumped.
TSS_{sieve} = air-dried mass of 63-µm sieved sediment/liters pumped.

The air-dried mass of sediment collected was not always adequate to conduct all planned analyses. In this case, analyses were prioritized as follows: PCBs, TOC, PCDD/Fs, PAHs, and arsenic. The final number of analyses for conventional parameters and contaminants is shown in Table 3. All centrifuged sediment samples were analyzed for TOC and PCBs. PCDD/Fs, PAHs, and arsenic were measured in 17-19 centrifuge, sieve, or Quality Control (QC) samples. Appendix E (Table E-2) lists all of the samples collected and analyses conducted.

Table 3. Number of water and suspended sediment analyses.

Sampling Dates (2008-09)	Water			Suspended Sediment											
	TSS	TOC	DOC	TOC		Solids		Total PCBs (Aroclors)		Dioxins/ Furans		PAH's		Arsenic	
				C	S	C	S	C	S	C	S	C	S	C	S
July 15-17	3	3	3	1	1	2	1	1	1	-	-	1	-	1	-
Aug 25-27	3	3	3	3	1	3	1	3	1	2	-	2	-	2	-
Sept 29-30	13 (1)	12 (1)	12 (1)	1	-	1	1	1 (1)	1	1	-	1	-	1	-
Oct 15-16	3	3	3	1	1	1	2	1	1	1	-	1	1	1	1
Nov 13*	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-
Nov 17-18	4 (1)	4 (1)	4 (1)	1 (1)	3	2	3	2 (1)	3	2 (2)	2	1 (1)	4	1 (1)	2
Dec 15-16	3	3	3	1	1	1	2	1	1	1		1	1	1	2
Jan 20-21	12 (1)	12 (1)	12 (1)	1	3	1	3	1 (1)	4	1 (1)	4	1 (1)	3	1 (1)	3
Total Number	44 (3)	43 (3)	43 (3)	9 (1)	10	11	13	10 (3)	12	8 (3)	6	8 (2)	9	7 (2)	8
QAPP Number	63	63	63	21		18		21 (3)		14 (3)		4 (1)		10 (1)	

* Whole water grab sample only, no separation of suspended sediment.
(#) = number of field blanks.
QAPP = Quality Assurance Project Plan.
C = centrifuge, S = sieve.

MEL measured Total PCBs as the sum of Aroclors in sediment extracts using a gas chromatograph equipped with an electron capture detector (EPA Method 8082). The concentration of PCBs was calculated according to the Sediment Management Standards rule (Ecology, 1991; revised 1995).

Pacific Rim Laboratories (PRL) measured 17 chlorinated PCDD/F congeners using high resolution gas chromatography/high resolution mass spectrometry (EPA Method 1613B). Toxic equivalents (TEQs) for these compounds were calculated using toxic equivalency factors (TEFs) published by the World Health Organization and required by Ecology (Van den Berg et al., 2006; Ecology 1990, revised 2007). A concentration of ½ the detection limit was assumed for undetected compounds.

MEL measured PAHs using capillary gas chromatography/mass spectrometry (SW 846 Method 8270). TEQ for the 7 cPAHs identified by Ecology (1990, revised 2007) were calculated using TEFs published by the State of California (Cal-EPA, 2005). The total TEQ for cPAHs was also calculated using ½ the detection limit for undetected compounds.

Arsenic was measured in samples digested with strong acid using an inductively-coupled plasma detector (EPA Method 200.8).

Deviations from the Quality Assurance Project Plan

Conditions that occurred during fieldwork forced minor deviations from the experimental design, sampling methods, and analysis procedures described in the QA Project Plan. These deviations did not affect the quality of the resulting data or the ability of the project to meet its objectives (see Data Quality).

The most substantial deviations from the QA Project Plan included:

- Suspended sediments were collected on 7 occasions, instead of 9 times.
- Distribution of suspended sediments within the channel was carefully ‘mapped’ only once, instead of several times during each sampling event.
- Sand-sized suspended sediments were separated and collected by sieving in the field, instead of post-processing centrifuged sediments to separate and collect the fine fraction.

Minor deviations from the QA Project Plan included:

- Current velocity and flow were measured during only 5 sampling events and sometimes with fewer than 4 transects.
- Particle size distribution was not measured in centrifuged or sieved sediment samples using standard laboratory methods (PSEP, 1986).
- The dry mass of centrifuged and sieved sediment samples was measured using an air-drying method (Donegan, 2004), instead of the more common method of measuring percent solids (PSEP, 1986; MEL, 2008).
- The total number of samples analyzed for each conventional parameter and contaminant differed from the planned number (Table 3).
- PCBs were calculated by summing Aroclor concentrations using EPA Method 8082.
- PAHs were measured using EPA Method 8270 SIM (with no isotopic dilution).

Loading calculations

Sediment loading

Daily loads

Daily suspended sediment loads were calculated from the mean daily flow at the Auburn gaging station and the TSS levels measured during this study. Sediment loads were predicted for other dates and flow conditions using a rating curve derived using the daily sediment load and corresponding mean daily flows measured during 1996-1998 at the USGS gaging station in Auburn (Embrey and Frans, 2003):

$$\mathbf{Ln\ (SS) = 12.6 + 1.8916 \times [\ln(Q/Q_{avg})] + 0.33201 \times [(\ln(Q/Q_{avg})]^2}$$

where

SS = daily suspended sediment load (mT).
Q = mean daily flow (cfs).
Q_{avg} = mean daily flow for the period of record = 1800 cfs.

Figure 2 shows the rating curve with daily sediment load expressed as concentration of suspended solids. The figure also displays most of the other suspended solids data available for the Green River. Reasons that these data were not used to calculate daily loads follow.

An earlier USGS study (Harper-Owes, 1981) was not used because the study:

- Assigned a single measured suspended sediment concentration (SSC) to as many as 31 consecutive days (note horizontal smearing of dots).
- Occurred just after Howard Hanson Dam operations began (October 1963 – June 1966) and the sediment load predicted for moderate to high flows during this period was significantly different from the apparent rate in the late 1990s ($p<0.05$).

Suspended solids data from King County (2009) and this study were not used because they both were likely to have underestimated concentrations of suspended sediment:

- Water samples were not depth-integrated.
- TSS was measured using EPA Method 2540D. [9]

Figure 2 provides evidence of this: most TSS results from these two studies fall below the depth-integrated SSC values collected by the USGS during 1996-1998.

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[9] TSS has been shown to underestimate the true concentration of solids, especially when flows resuspend and transport larger particles (Guo, 2006; Gray et al., 2000).

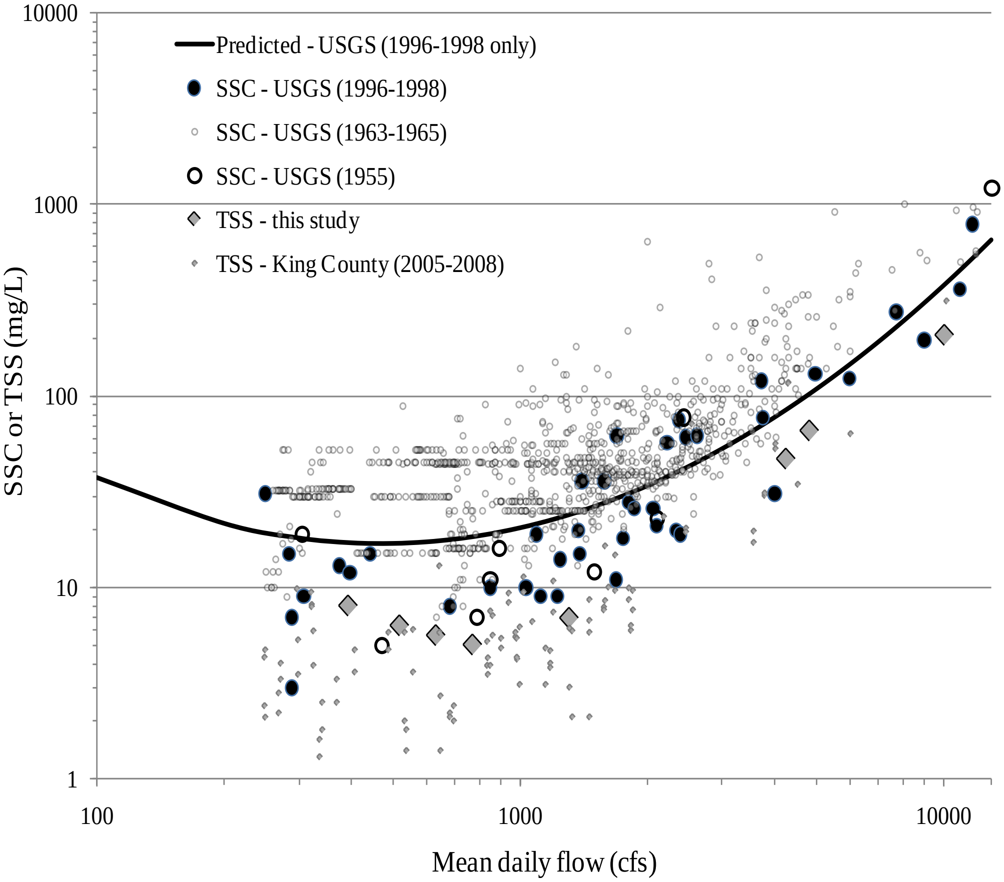

Figure 2. Rating curve for suspended solids concentrations (SSC) in the Green River at Auburn, Washington.

Annual loads

Annual sediment loads were calculated by summing the daily loads, each predicted using the rating equation listed above, for a calendar year. The example shown in Table F-1 shows that an estimated 218,000 metric tons (mT) of suspended sediment was delivered from the Green River to the LDW in 1975. This calculation was repeated for each year of the 30-year period used in the STM (1960-1989).

Contaminant Loading

Daily loads

Daily contaminant loads were calculated for each of the 7 sampling events. Contaminant levels measured in the centrifuged sediment samples were multiplied by the daily sediment load calculated from TSS measured in composited river samples and mean daily flows (USGS, 2009).

Annual loads

The limited number of analytical results for suspended sediment-associated contaminants did not warrant a detailed examination of annual contaminant loading. However, *approximate* lower- and upper-bound values were calculated. This was done by summing all daily contaminant loads for a year, each obtained by multiplying a predicted contaminant concentration by the daily sediment loads.

Prediction of daily contaminant concentrations was done using regression equations relating contaminants measured in the centrifuged sediment samples and mean daily flows.[10] The latter parameter was found to explain the greatest proportion of the observed variability.

Data quality

This section describes how data quality was evaluated and summarizes results of the data quality review. The data that form the basis of the evaluation are presented in the Results section, appendices, or are available upon request.

Representativeness

Samples were generally representative of sediments suspended mid-channel in the Green River that would have entered the LDW. This judgment was based on elements of the study design, choice of field methods, field measurements (Appendix D), and validated analytical results. Some of these are listed below:

- Only a small fraction of the of the Green River's annual flow enters the LDW below the USGS gaging station at Auburn (LDWG, 2008; King County, 2009). Time-averaged flows appeared to confirm that flow originating downstream of Auburn was inconsequential (Figure D-2).
- The sampling site, by virtue of its location, captured nearly all upstream sources of suspended sediment and contaminants entering the LDW.
- Pump intakes were maintained at least 1 foot above the bottom to avoid collecting material moving along the river bed (bed load).
- The water column was well-mixed during most flows (Figure D-3a through Figure D-3d). This was even true when a distinct saline layer was observed (Figure D-3e).
- Collecting water from depths where current velocities were greater than the channel average (Figure D-4) partly compensated for not sampling in a truly depth-integrated manner.
- The sampling location was minimally influenced by downstream contaminant sources.
    - Intrusion of saline water was limited to low flows and flood tides (Figure D-5a through Figure D-5d).

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[10] Correlations and regression relationships between various parameters (TSS and flow, contaminants and flow, and contaminants and conventionals) were explored with standard statistical software and methods using SPSS 11 and SYSTAT 11 software.

  - Pump intake depth was maintained above any distinct saline layer present. Episodes of elevated salinity at the pump intake depth were limited in number and duration (Figures 4 and D-6).
  - Upstream transport of suspended sediment occurred during flow reversals (periods of low flow and strong flood tides), but particle concentrations and sizes were reduced (Figure D-7). These finer suspended particles may have been oversampled but would have eventually entered the LDW.
- Most seasonal variability in suspended sediment concentrations (5-76 mg TSS/L) was captured by 7 sampling events covering a wide range of flow conditions (391-4,800 cfs).[11]
- Short-term temporal variability in suspended sediment concentrations was captured by centrifuging suspended sediment throughout full tidal cycles (24 or 48 hours).
- Spatial variability in suspended sediment concentrations was partly addressed:
  - The sampling location and channel geometry provided a well-mixed water column.
  - ADCP measurements of current velocities at the sampling location confirmed that channel characteristics ensured a relatively well-mixed water column during most flows.
  - The water column was generally dominated by particles small enough (modal size 10-30 µm) to be uniformly suspended and easily resuspended under most current velocities.
  - Although not truly depth integrated, water was pumped from different distances below the surface and above the bottom during each event. This was by virtue of maintaining pump sampling depth at approximately 0.6 times the mid-channel maximum regardless of flow and tidal phase.
- Pump sampling did not result in TSS and TOC concentrations appreciably different from those measured in discrete or composited river water samples collected with a Kemmerer bottle (see Results and Appendix E).
- The centrifuges retained a high percentage of the influent TSS, with only some of the finest particles passing through in the effluent (Figure D-8).
- Sieved samples effectively separated sand-sized particles (>63 µm) from finer particles. Resuspended subsamples, analyzed using the LISST-Streamside, contained a relatively small fraction of suspended sediment less than the mesh size of the sieve (Figure D-9).

Reasons that the samples collected and contaminant concentrations reported may *not* have been representative of suspended sediment entering the LDW include:

- No sampling occurred during spring seasonal flows.
- No suspended sediment was collected during the rising stage of high-flow events.
- Samples were not truly depth-integrated. Pump sampling water from a single target depth may underestimate the concentration of suspended sediments, especially sand-sized particles.

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[11] Grabs samples collected in November 2008, at flows of approximately 10,000 cfs, had TSS of 209 mg/L.

- Samples may have over-represented sand-sized suspended sediments because current velocity at 0.6 times the maximum mid-channel depth was 27% greater than in the channel overall (Figure D-4).
- Collecting time-integrated samples (pump sampling for 24-48 hours) may have biased sampling toward collection of suspended sediments capable of being transported upstream during flood tides.

Comparability

Sampling protocols and sample acceptance guidelines were consistent with ones used previously (Ecology; 2008; PSEP, 1997a; Seiders, 1990; Serdar et al., 1994; Serdar, 1997a, 1997b).

Methods and standard operating procedures (SOPs) for laboratory analysis were the same as those used throughout the region for water and sediment quality studies (APHA, 2005; Ecology, 2008; MEL, 2008; PSEP, 1986, 1997b, and 1997c).

The analytical method used in this study to measure TSS can underestimate true concentrations of suspended solids. This appears to be especially true for samples containing appreciable sand-sized particles. Although similar, the method used to measure SSC (ASTM, 1997) may yield more accurate results for such samples (Guo, 2006; Gray et al., 2000). Therefore, TSS results from this study, particularly for samples collected during the high flows of November 2008 and January 2009, may not be comparable to SSC values reported by the USGS.

Acceptability

Ecology staff has reviewed all field measurements and laboratory analytical results for exceedances of holding times and deviations from required protocols. QC sample results were compared to measurement quality objectives listed in the QA Project Plan (Gries and Sloan, 2008). Thus far, substantive issues with field measurements, water sampling, or laboratory analyses have not been identified. Most results have been found to be acceptable for use without qualification.

The sensitivity of field measurements and laboratory analyses was acceptable because required reporting limits were achieved.

Precision of field and laboratory measurements was assessed as relative percent differences (RPD) or relative standard deviations (RSD) for replicates, as well as matrix spike duplicates. Precision was acceptable, except as follows:

- Replicate measurements of total flow sometimes exceeded the recommended ±5% of the mean.
- Specific conductivity and salinity was sometimes highly variable at specific depths during a flood tide when mean daily flow was <1,000 cfs.
- LISST measurements of particle size distribution of discrete water samples sometimes required multiple readings to obtain repeatable results.

- Some results for PAH compounds were qualified as estimates because matrix spike samples showed low recovery or laboratory duplicates were outside acceptable RPD limits.

Analytical bias and matrix effects were not evident from laboratory control, surrogate spike, and matrix spike sample results.

Accuracy of results for PCDD/F in sediment samples was acceptable, based on the recoveries of a certified reference material. The accuracy of results for total PCBs, PAHs, and arsenic could not be evaluated because reference materials were not used when analyzing these parameters.

The following specific data quality issues were identified:

- Field blanks (water) showed high DOC levels on 2 occasions. However, this was due to residual methanol from cleaning the centrifuge flow control equipment. No contaminants were detected.
- Results for TOC in several of the centrifuged and sieved sediment samples were qualified as estimates because the holding time was exceeded.
- Results for total PCBs in sediment samples were qualified as estimates because:
    - Holding times were exceeded (6 samples only).
    - Continuing calibration verifications showed electron capture detector response drifted after exposure to the sediment matrix (possible high bias).
    - Concentrations were less than the reporting limit.
    - There was uncertainty about Aroclor identifications for some low level results.
- Some results for individual PCDD/F congeners were qualified as estimates because they were less than the reporting limit.
- PAHs were re-analyzed in one sieved sediment sample due to an unusual result. The earlier result was due to mislabeling the matrix spike sample.

In addition to the data quality review conducted by Ecology staff, the majority of laboratory results of the study are also undergoing full validation by EPA chemists. Results of the validation effort, when completed, will be made available on request. Thus far, no major quality concerns have been identified.

Data usability

Data were assessed for usability, as described in the QA Project Plan, and entered into EIM as appropriate. Results contained in EIM will be updated, if necessary, when EPA completes data validation. Field notes, observations, and measurements were also entered into a Microsoft Access 2007 database developed specifically for the study (Appendix C).

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Results and Discussion

Field measurements

Stage height and water depth

Values recorded from the staff gage ranged from <0.0-3.1 meters (<0.0-10.1 feet). The relative stage height tracked predicted tidal elevations except during high flow combined with low tide (Figure D-1). Water depth measurements ranged from 0.9-4.0 meters (3.0-13.0 feet), and could change by as much as 3.0 meters (10.0 feet) during a sampling event.

Flows

Mean daily flow at the USGS station in Auburn, calculated from real-time records, ranged from 10-135 cms (390-4,800 cfs) during the 7 sampling events. Flow was 285 cms (10,000 cfs) on November 13, 2008, when discrete water samples were collected for analysis of conventional parameters. These flows represented 24th-98th percentile values for long-term mean daily flows. All but one sampling occurred when flow was greater than the median for that time of year (Figure 3).

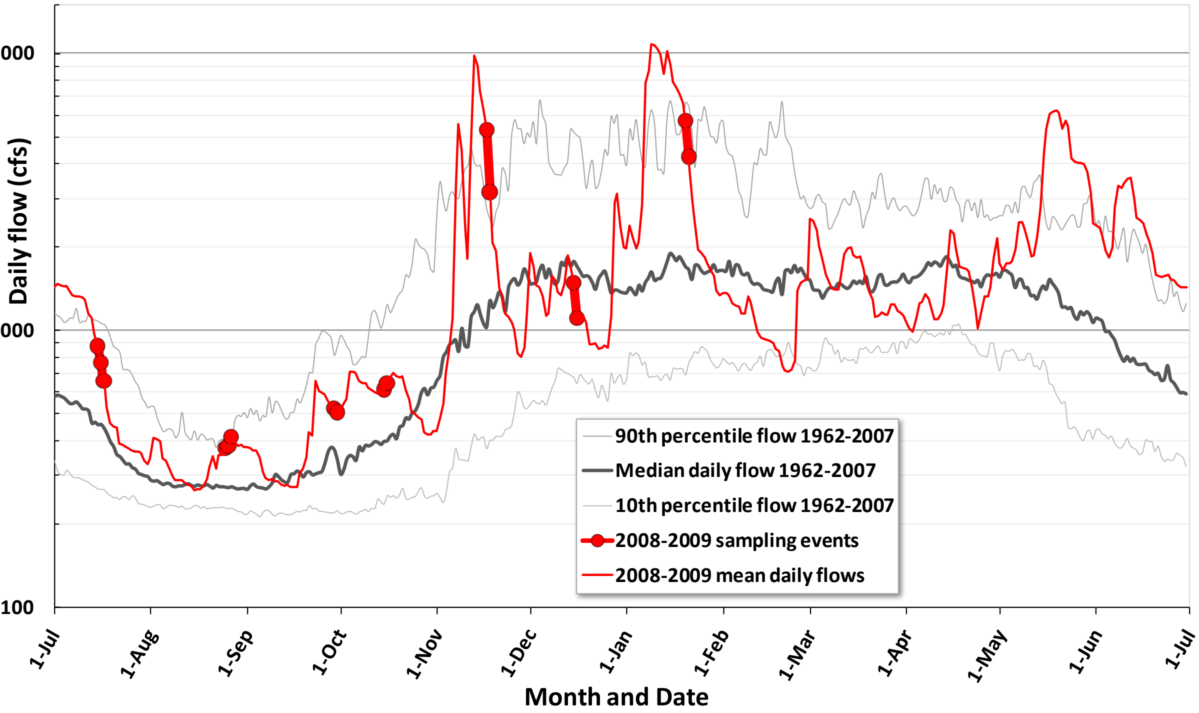

Figure 3. Mean daily flow in the Green River at the USGS gaging station in Auburn.

Flows measured at the sampling site during the high-flow sampling events in November 2008 and January 2009 mirrored the mean daily flows predicted at the Auburn gaging station (Figure D-2). Tidally-influenced changes in flow during the low-flow sampling events were substantial, but the mean daily flow appeared to be only slightly greater than at Auburn.

Current velocity

Post-processed velocity data showed the mean current velocity near the pump was 0.56 meters per second (1.84 feet per second). The difference from the mean channel velocity of 0.46 m/sec (1.50 fps) was significant ($p<0.05$; Figure D-4). For paired measurements, current velocity near the pump was 27% greater than the channel velocity. Sampling thus appeared to usually occur at a depth where suspended sediment concentrations may have exceeded the channel average.

Salinity

Salinity profiles are shown in Appendix D. When the profiles show appreciable salinity, they most often indicated a linear dilution of saline bottom water, intruding from downstream, with overlying fresh river water. The August profiles did show that a distinct layer or 'salt wedge' was present for a short period of time. The pump intake depth was maintained above such distinct saline layers.

Figure 3 summarizes salinities measured at the pump intake depth, and is based on the vertical salinity profiles provided in Figure D-5a through Figure D-5d. The highest salinity values recorded for the pump intake depth, 5-8 ppT, occurred for about 15% (7 hours) of the 47-hour August sampling. Water of nearly 3 (ppT) salinity was sometimes pumped during the September and October samplings.

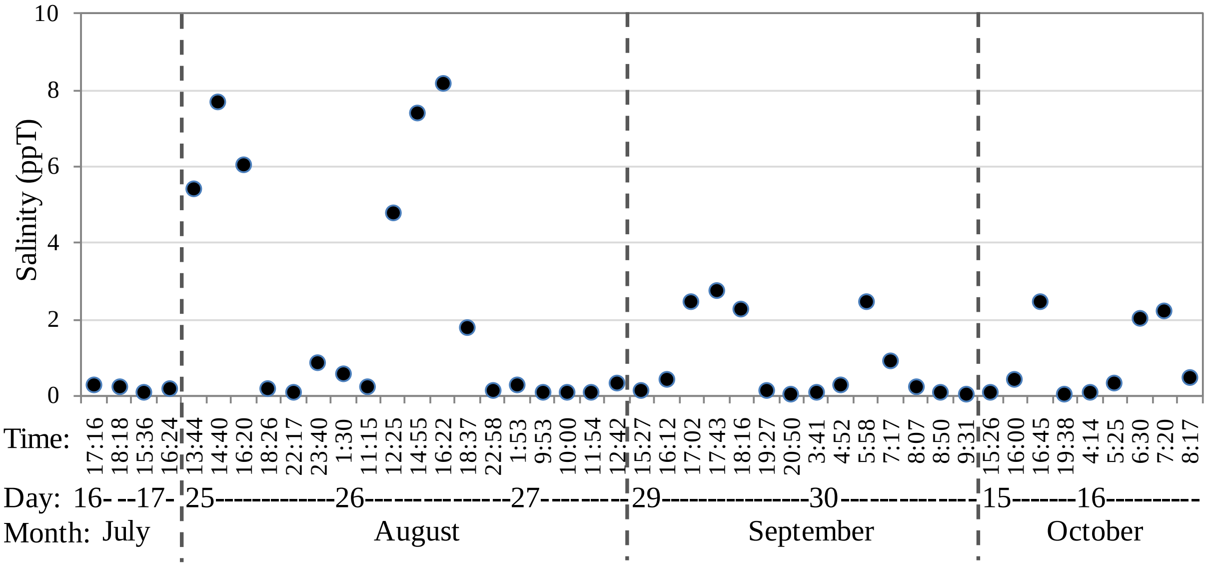

Figure 4. Summary of salinity levels measured at depth of pump deployment, 2008.

Pump depth

The pump intake depth was adjusted to the target depth of 0.6 times the maximum mid-channel depth with little difficulty. However, actual pump depth often differed from this target just before being adjusted to rapidly changing water levels (strong ebb or flood tides). Over 90% of the pump depth records were between 40% and 80% of the maximum depth (Figure D-6).

In-situ suspended sediments

Results of LISST measurements showed the following:

- The modal size of suspended sediment at the sampling site was that of very fine to medium silts (10-30 µm diameter particles).
- The concentration and mean particle size of suspended sediment:
    - Increased with increasing current velocities (high flows, ebb tides)
    - Decreased with decreasing current velocities (low flows and flood or slack tides)
    - Decreased when flow was reversed (compared to periods od downstream transport). See Figure D-7.
- Continuous-flow centrifuges retained all but a small fraction of the finest suspended sediment particles (Figure D-8).
- Suspended sediment particles <63 µm in diameter that were retained on sieves were a small fraction of the total (Figure D-9).

Most field measurements are summarized in Appendix D. Complete field results are available electronically (Microsoft Access database format).

Laboratory results

Detailed analytical results for the water and sediment samples described in this section are provided in Appendix E. They are also available by searching for the Study ID LDW_08 in the EIM database (www.ecy.wa.gov/eim/).

Water samples

The range of TSS in composited Green River water samples for the 7 sampling events was 5.0-66 mg/L. Figure 5 shows that concentrations approximated the 30th-92nd percentile values for TSS and the 2nd-78th percentile values for suspended solids concentration (SSC). Discrete water samples collected on November 13, when flow was 285 cms (10,000 cfs), contained 209 mg/L TSS.

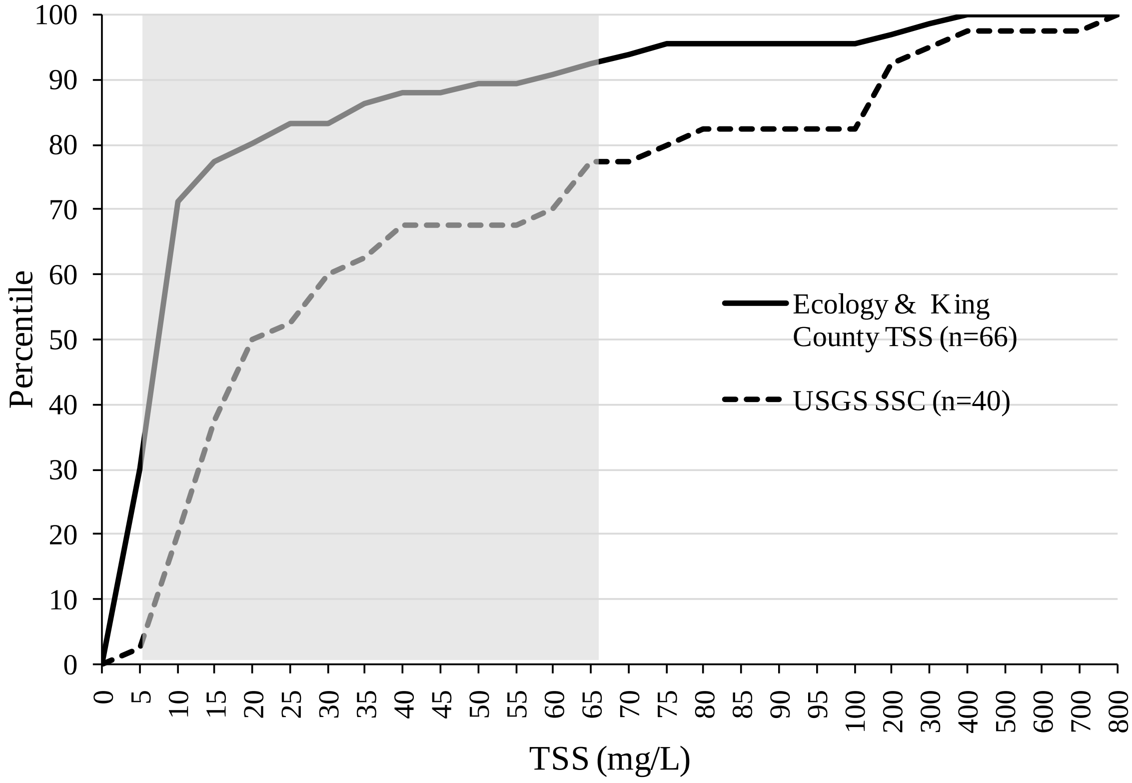

Figure 5. Cumulative frequency distributions for TSS and SSC in the Green River.

The shaded area was the range of TSS measured during this study. The TSS curve was derived from the results of this study and from King County (2009). The SSC values were USGS measurements (Embrey and Frans, 2003).

TOC concentrations in composited river water samples (1.3-2.5 mg/L) were indistinguishable from the TOC in composited influent samples, with January samples the exception. DOC (1.1-2.1 mg/L) comprised 77-95% of TOC. Particulate organic carbon (POC) in the channel, calculated by difference, was calculated to be 0.1-0.6 mg/L.

Proof of methods

Conventional parameters were measured as potential predictors of contaminants, but also to evaluate sampling methods and centrifuge efficiency. Some results are summarized below.

- Pumped samples that were composited had an average of 12% greater TSS than similarly composited grab samples collected at the same location and time. This could be explained by rapid settling and incomplete sampling of larger particles in the Kemmerer bottle. It was also possible that particles were oversampled because the pump rate created influent current velocities different from those in the channel.
- Centrifuges removed TSS with 92%-99% efficiency when the influent flow rate was kept at about 3.0 liters (0.8 gallons) per minute (Table 4). This was consistent with but surpassed Horowitz et al. (1989) that showed continuous-flow centrifuges could remove

>85% of suspended particles greater than 0.45µm in diameter. LISST measurements showed that the size range of particles that passed through the centrifuges and appeared in the effluent was 4-25 µm, with the mean size between 10-15 µm (Figure D-8).

Table 4. Centrifuge efficiency for 7 centrifuge sampling events.

Sampling event 2008-09	Influent TSS (mg/L)	Effluent TSS (mg/L)	Efficiency (% TSS retained)
July	5	0.4 U	92
August	10	0.5	95
September	7.1	0.3 U	95.8
October	6.7	0.3 U	95.5
November	56.5	0.4	99.3
December	6.4	0.3	95.3
January	76	1.0 U	98.7

The full reporting limit (RL) was used in calculations when effluent TSS was undetected (U).

Centrifuged sediments

The pump and centrifuge sampling system collected 39-722 air-dried grams of suspended sediment per day, depending entirely on the level of TSS in the influent (Figure 6). The figure corroborates the high efficiencies that were realized.

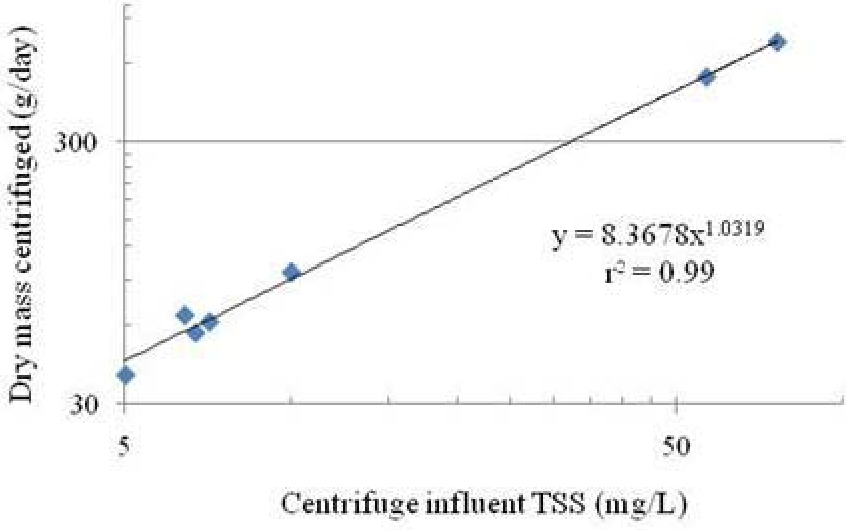

Figure 6. Mass of centrifuged sediments collected as a function of influent TSS.

Concentration of fines, TOC, and contaminants associated with centrifuged sediment samples are summarized in Figure 7, Figure 8, and Table 5. Suspended sediments overall contained 79.2-93.7% fines, values similar to those measured in 1996-1997 but much greater than values reported in 1965 (LDWG, 2008). TOC in the 7 samples ranged from 1.72 to 6.01%, averaging 4.3%. Two studies of bedded sediments located upstream of the turning basin (LDWG, 2007; Longtine, 2009) reported mean TOC values of 0.86% and 1.60% that were significantly lower ($p<0.05$). This indicated that substantially more suspended organic material is transported downstream into the LDW than settles out upstream.

Dry weight concentrations of total PCBs ranged from undetected (1.2 µg/kg) to an estimated 62.1 µg/kg. Aroclors 1248, 1254, and 1260 were detected in samples collected from July through October, but not thereafter. The total TEQ associated with the 17 PCDD/Fs that were measured was 0.83 - 16.2 ng /kg. cPAH concentrations ranged from an estimated 13.1 to 588 µg TEQ /kg. Arsenic concentrations were 9.2 - 24.3 mg/kg. The highest concentrations of total PCBs, arsenic, and PAHs in the centrifuged sediments did not approach the Sediment Quality Standards (SQS).

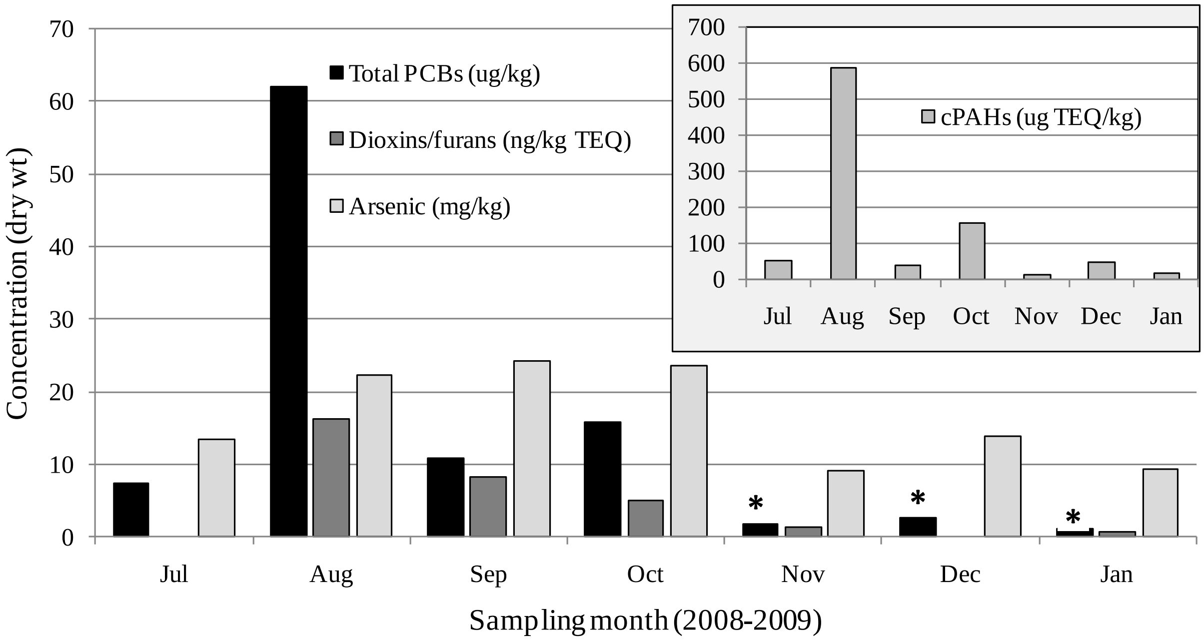

Figure 7. Contaminants associated with suspended sediments collected by pump and centrifuge from the Green River.

** = Not detected at reporting limit plotted.*

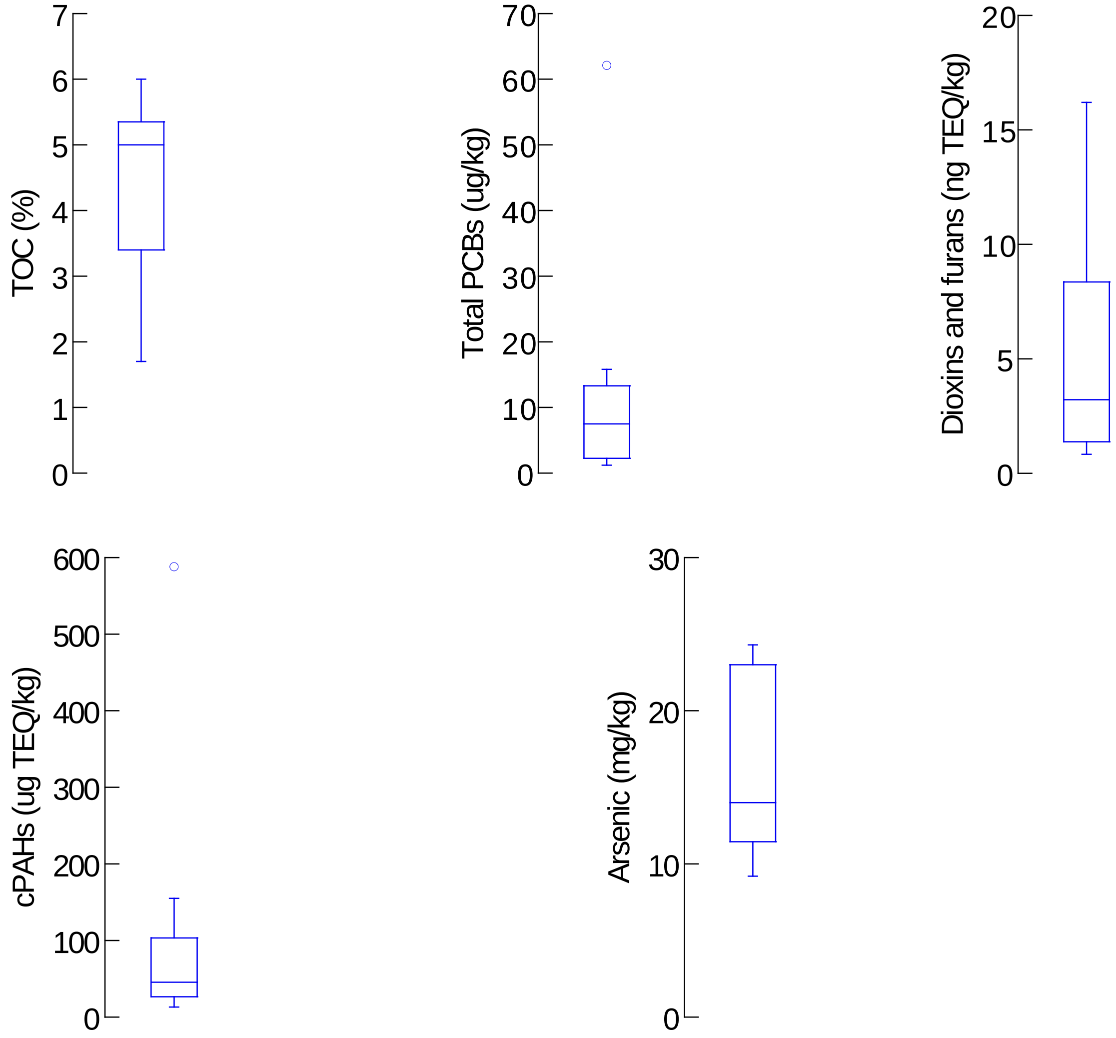

Figure 8. Box plots for concentrations of TOC and priority contaminants measured in suspended sediment centrifuged from the Green River.

The median value is represented by the horizontal bar located between the 25th percentile value (bottom of box) and 75th percentile value (top of box). Vertical lines show the range for all observations except potential outliers (circles). Potential outliers were not removed before analysis.

Table 5. Summary of laboratory results for suspended sediments collected by centrifugation. *Field duplicate results were averaged. For statistics, results were treated as if not qualified.*

Parameter (dry wt)	n	No. of detects	Minimum	Median	Mean	s	90th Percentile	Maximum
% Fines (calculated)	7	7	79.2	87.2	86.0	6.0	93.1	93.7
TOC (%)	7	7	1.72	5.0	4.3	1.7	5.6	6.01
Total PCBs (µg/kg)	7	4	1.2 U	7.5	14.7 J	21.6	34.3	62.1 J *
PCDD/F (ng TEQ/kg)	6	6	0.83	3.22	5.53	6.0	12.3	16.2
cPAHs (µg TEQ/kg)	6	6	13.1 J	45.5	130	208	330	590
Arsenic (mg/kg)	7	7	9.2	14.0	16.6	6.6	23.9	24.3

n = number of samples, s = standard deviation (from mean), CV = coefficient of variation.
J = estimated value, U = not detected at reporting limit.
* = maximum value reported for total PCBs is adjusted for the concentration measured separately on material collected from centrifuge disks.

Contaminant and TOC concentrations were greatest when daily flow was below the annual mean (<38 cms or <1,330 cfs). Maximum organic contaminant concentrations were measured in samples collected during the August sampling. The August sampling featured low flows and a short, intense local rain event that caused visible stormwater discharges and visibly increased turbidity for several hours.

Suspended sediments associated with the high flows of the November 2008 and January 2009 sampling events contained low or undetectable concentrations of contaminants and TOC (Figure 7). Total PCBs were not detected, even at low reporting limits during the last 3 months of the study. Lower TOC concentrations were due in part to dilution with mineral sediments suspended by the higher flows. This was reflected in the greater % sands measured in November – January centrifuge samples (Figure 9). Concentrations of total PCBs were probably undetectable in these later sampling events for two reasons:

- High-flow and load events associated with discharges from the Howard Hanson Dam or runoff from the upper watershed *normally* contain no or low concentrations of organic contaminants and TOC.
- The late season sampling events followed the rising stage of high-flow events that had already flushed available sediment-associated contaminants from the watershed.

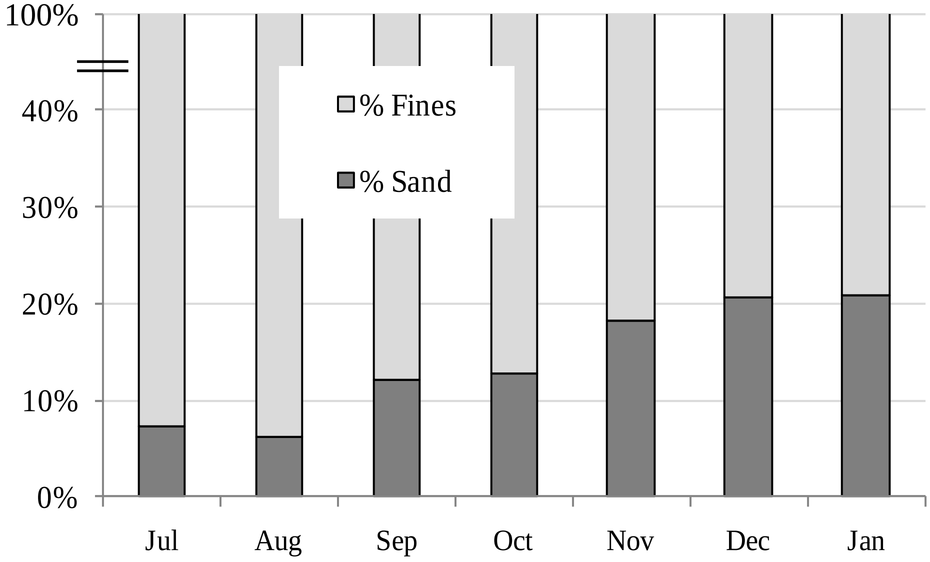

Figure 9. Partitioning of sands and fines (clays and silts) in suspended sediment from the Green River.

Sieved sediments

Measurements of particle size distributions of subsamples of sieved sediments were made using the LISST instrument. Results confirmed that the field sieving procedures effectively collected the suspended sand-sized particles and allowed nearly all silt and clay particles (<63 µm) to pass through. Depending on TSS levels and the rate of pumped flow, 2.8-171 air-dried grams of material were collected on sieves each day. The dry mass collected during each sampling event determined whether TOC and priority contaminants were measured. Concentrations measured in the sieved material were then used to calculate levels associated with the fine-sized fraction of suspended sediments (<63 µm) as follows:

$$C_f = [(C_c * TSS_c) - (C_s * TSS_s)]/TSS_f$$

C_f = estimated concentration associated with fine particles (<63 µm).
C_c = centrifuged sample concentration (measured, all particle sizes).
TSS_c = centrifuged solids (air-dried mass/liters pumped, assuming ≈ 100% efficiency).
C_s = Sieved A sample concentration (measured, >63 µm particles).
TSS_s = sieved fraction (aired-dried mass/liter pumped) = TSS_s/TSS_c).
$TSS_f = TSS_c - TSS_s$.

Carbon

TOC content of the sieved samples ranged from 1.63% (estimated) to 9.62%, and was sometimes substantially greater than the TOC in the centrifuged samples. TOC concentrations were greatest during low flows and least during high flows. This could be ascribed to the presence of low specific gravity plankton and organic debris, accompanied by relatively less suspended mineral material having greater specific gravity. Sieved samples, representing the sand-sized fraction of suspended sediment, usually contained greater TOC than what was calculated for the fine fraction (Figure 10). The likely explanation for this was that fine suspended material was composed primarily of mineral material.

Contaminants

Results showed that contaminant concentrations measured in sieved samples were usually (9 of 13 instances) lower than the concentrations calculated for the fines fraction. Differences in concentrations of organic contaminants associated with the different size classes of particles, however, were often relatively small and in one case not consistent. Differences in arsenic concentrations between the two size classes were more convincing.

Total PCB concentrations in sieved sediments were similar to centrifuged sediments. Sieved samples collected during July and August contained somewhat greater PCBs than the concentrations calculated for the co-occurring fine suspended sediments. The opposite was true for sieved sediment samples collected during September and October.

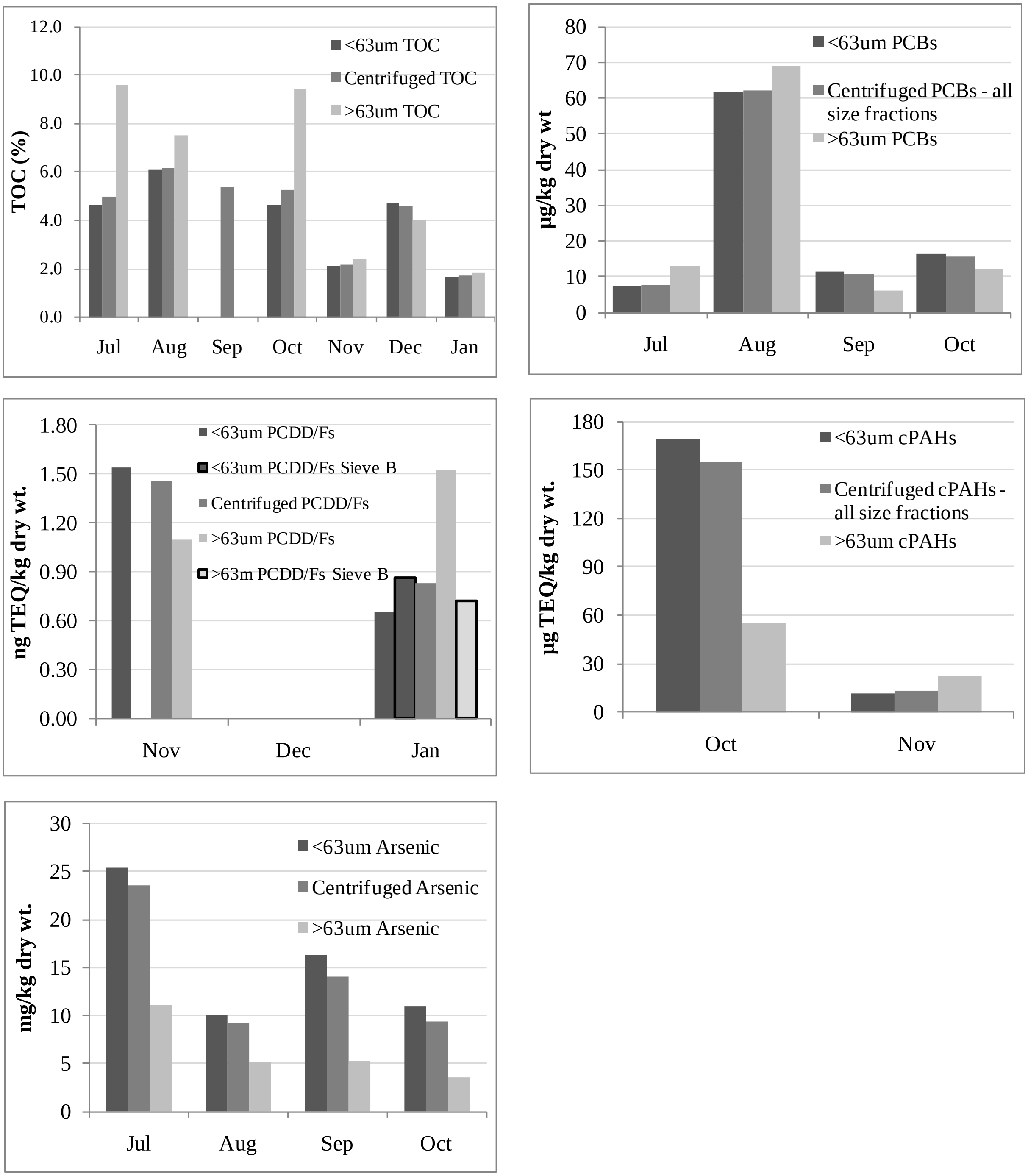

Figure 10. TOC and contaminants associated with different size fractions of suspended sediment.

Contaminant concentrations in centrifuged samples (all size fractions of suspended sediments) are shown as the middle bar in each grouping. Concentrations calculated for the fine fraction of suspended sediments are shown on the left. Concentrations measured in sieved samples (Sieve A except as noted) appear on the right.

PCDD/F levels were only measured in sieved sediment samples collected during 2 sampling events. In November, the calculated concentration of PCDD/Fs in fine suspended sediment (1.54 ng TEQ/kg) was greater than the concentration measured in the sieved sample (1.10 ng TEQ/kg). Results for samples collected in January were inconsistent relative to the concentration of 0.83 ng TEQ/kg PCDD/Fs measured in the centrifuged sediment sample. The 1.52 ng TEQ/kg PCDD/Fs measured in the Sieve A sample was greater than the 0.65 ng TEQ/kg concentration calculated for fine suspended sediment. In contrast, the Sieve B sample contained a lower concentration of PCDD/Fs (0.73 ng TEQ/kg) than calculated concentration for fine sediment (0.87 ng TEQ/kg). The difference may have been influenced by different pumping rates.

Concentrations of cPAH in sieved samples were 18.5-67.1 µg TEQ/kg dry weight. The fine fraction of the October sample was calculated to have more cPAHs than the sieved sample. The opposite was true for the November sample, but differences were small.

Arsenic concentrations ranged from 9.2 to 24.3 mg/kg dry weight in suspended sediment collected by the centrifuges and from 3.57 to 11.1 mg/kg dry weight in sieved samples. Arsenic was measured in both the centrifuged and sieved samples collected on 4 occasions. Results showed the mean concentration calculated for fine suspended sediment (15.7 mg/kg) was significantly greater than the mean concentration for sand-sized suspended sediment (6.3 mg/kg, $p<0.05$).

Overall, levels of contaminants calculated for 9 of 13 samples of fine-sized sediments were consistent with the theory and findings of other studies.

- Pierard et al. (1996) measured PCB congeners in 5 sediment grain size fractions. Most PCBs were associated with the finest fraction of coastal sediments and larger plant-derived particles.
- Carro et al. (2002) showed that 10 PCB congeners were usually, but not always, associated with the finest fractions of coastal sediments.
- Kukkonen et al. (2003) noted that the highest concentrations of 2 PAH compounds were usually associated with the finest particles (<20 µm) collected from 6 Midwest lake sediments.
- Lee et al. (2006) showed that levels of PCDD/F in marine sediments increased as particle size decreased (and as TOC increased).

However, relationships between nonpolar organic contaminants and particle size (or TOC) are not always clear. Petrena et al. (2002) showed that mineralogical composition of sediments and sources of organic matter both played a role in partitioning of PCBs. Burgess et al. (2001) concluded that lindane and some PCBs were most related to organic carbon in sediments while fluoranthene was closely linked to silt content. Klamer et al. (1990) reported good relationships between nonpolar organics in <16 um material from a Dutch tide flat, but also noted that significant PAHs could occur in the >63 um fraction of marine sediments. These studies provide possible explanations for results less consistent with theory and expectations.

Relationships between parameters

Spearman rank correlation analysis was used to explore relationships between various parameters measured in the field and characteristics of centrifuged sediment. Significant correlations are shown in Table 6. The parameters that most frequently exhibited significant correlations with other parameters, and therefore became candidates for use as independent predictor variables, were:

- Mean daily flow.
- % fines in centrifuged sediment samples.
- POC in river water or centrifuged sediment samples.

Neither % fines nor POC in river water was measured but was instead calculated from other results. Therefore, mean daily flow and TOC in centrifuged samples were chosen as potential independent predictor variables in regression analysis that might predict contaminant concentrations. It was ultimately determined that regressions between priority contaminants and flow tended to explain more of the observed variability in contaminant concentrations than centrifuged TOC (or TSS).[12]

The strength of the regression relationships derived from results of this study, however, should be viewed with some caution because:

- The sample size for regressions involving contaminants was limited (7 composite samples).
- Results for the two high-flow sampling events exhibit a large influence on the regressions.
- Contaminants were not measured in suspended sediment samples collected during the rising stage of high-flow events.
- A larger sample size, especially one that included samples collected during the rising stage of high-flow events, would very likely result in different regression relationships.

For the reasons stated above, the regressions shown in Figures 11 a-d were only used to calculate *approximate* lower-and upper-bound estimates of annual contaminant loads associated with suspended sediments.

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[12] For example, predicting concentrations of total PCBs using flow, TSS, and TOC in the centrifuged sediment samples explained 80%, 44%, and 52% of the observed variability.

Table 6. Spearman rank correlations between various parameters measured in water and suspended sediments of the Green River.

Daily Flow	1													
TSS River	0.50	1												
TOC River	0.25	0.72	1											
TOC Influent	-0.23	0.23	**0.76**	1										
POC River	**0.87**	0.60	0.51	0.13	1									
POC Influent	-0.26	0.39	0.67	**0.82**	0.14	1								
TOC Sieve	-0.77	**-0.94**	-0.54	-0.06	-0.75	-0.27	1							
Fines Cent	**-0.86**	-0.54	-0.13	0.25	-0.73	0.34	0.77	1						
TOC Cent	**-1.00**	-0.50	-0.25	0.23	**-0.87**	0.26	0.77	**0.86**	1					
PCBs Cent	**-0.96**	-0.54	-0.31	0.18	**-0.95**	0.16	0.77	**0.82**	**0.96**	1				
PCBs – OC Cent	**-0.86**	-0.36	-0.27	0.11	**-0.84**	0.34	0.80	**0.82**	**0.86**	**0.89**	1			
PCDD/Fs Cent	**-0.94**	-0.49	-0.03	0.37	-0.72	0.52	0.80	**1.00**	**0.94**	**0.89**	**0.89**	1		
cPAHs Cent	-0.75	-0.54	-0.34	-0.05	**-0.93**	-0.22	0.71	0.68	0.75	**0.86**	0.68	0.60	1	
Arsenic Cent	**-0.82**	-0.54	-0.58	-0.09	**-0.78**	-0.10	0.60	0.45	**0.82**	**0.79**	0.61	0.66	0.57	1
	Daily Flow	TSS River	TOC River	TOC Influent	POC River	POC Influent	TOC Sieve	Fines Cent	TOC Cent	PCBs Cent	PCBs – OC Cent	PCDD/Fs Cent	cPAHs Cent	Arsenic Cent

Cent = centrifuged sediment sample.
PCBs – OC = total PCBs normalized to % TOC.
Bold font = significant at $p<0.05$.
Bold and underlined font = significant at $p<0.01$.

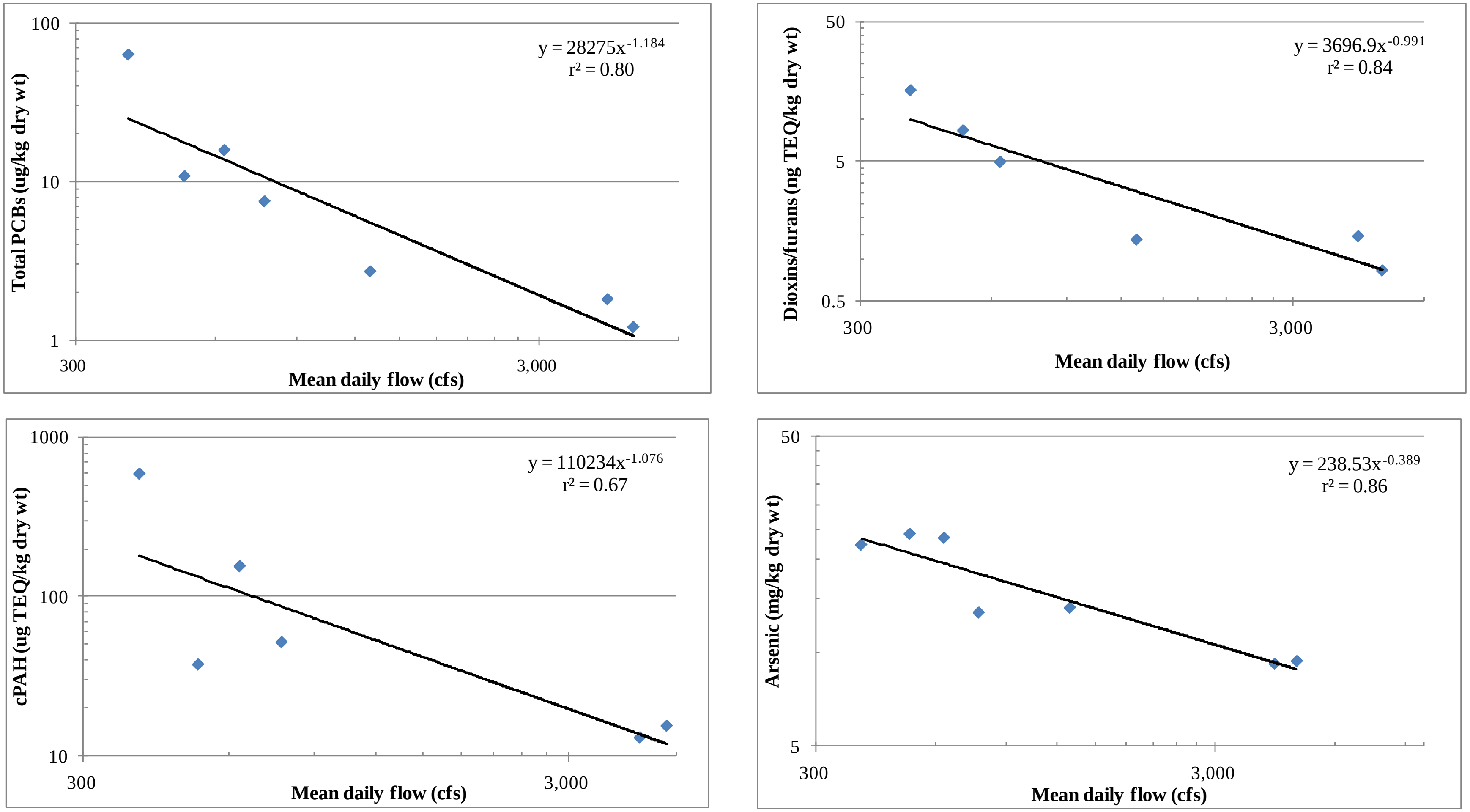

Figure 11. Regression relationships between concentrations of suspended sediment contaminant and mean daily flows.

Load estimates

Sediment loads

Daily sediment loading

Daily loads of suspended sediment measured during the 7 centrifuge sampling events are shown in Table 7. The difference between minimum and maximum observed daily loads was nearly an order of magnitude. The daily load on November 13, 2008, when mean daily flow was >280 cms (10,000 cfs) and TSS was 209 mg/L, likely exceeded 5,100 mT.

Table 7. Daily sediment loads calculated for the Green River near Tukwila, Washington, 2008-09.

Parameter	Sampling Month						
	July	August	September	October	November	December	January
Flow (cfs)	769	391	517	630	4,225	1,300	4,800
Flow (cms)	21.8	11.1	14.6	17.8	120	36.8	136
TSS in pumped river water (mg/L)	5.0	10.0	7.1	6.7	56.5	6.4	76
Sediment load (mT/day)	9.4	9.6	9.0	10.3	586	20.3	893

cfs = cubic feet of water per second.
cms = cubic meters of water per second.
TSS (mg/L) = milligrams per liter of total suspended solids.
mT = metric tons (1000 kg or 2200 pounds).

Annual sediment loading

The STM used a similar equation to predict daily load of SSC only when the daily flow was greater than the long-term mean daily flow (1330 cfs). However, the STM adjusted the coefficient from 12.6 to 13.4 to better explain the observed accumulation of sediment within the LDW cleanup site.

Annual sediment loads of suspended sediment calculated for the 30-year period used in the STM (1960-1989) ranged from 21,400 to 218,000 metric tons (Figure 12). The mean annual load for the period was of 74,700 mT (± 16,100 mT 95% confidence interval). This was approximately 48% of the estimate presented in the STM (157,000 mT). The difference was mostly due to use of the unmodified USGS coefficient (12.6).

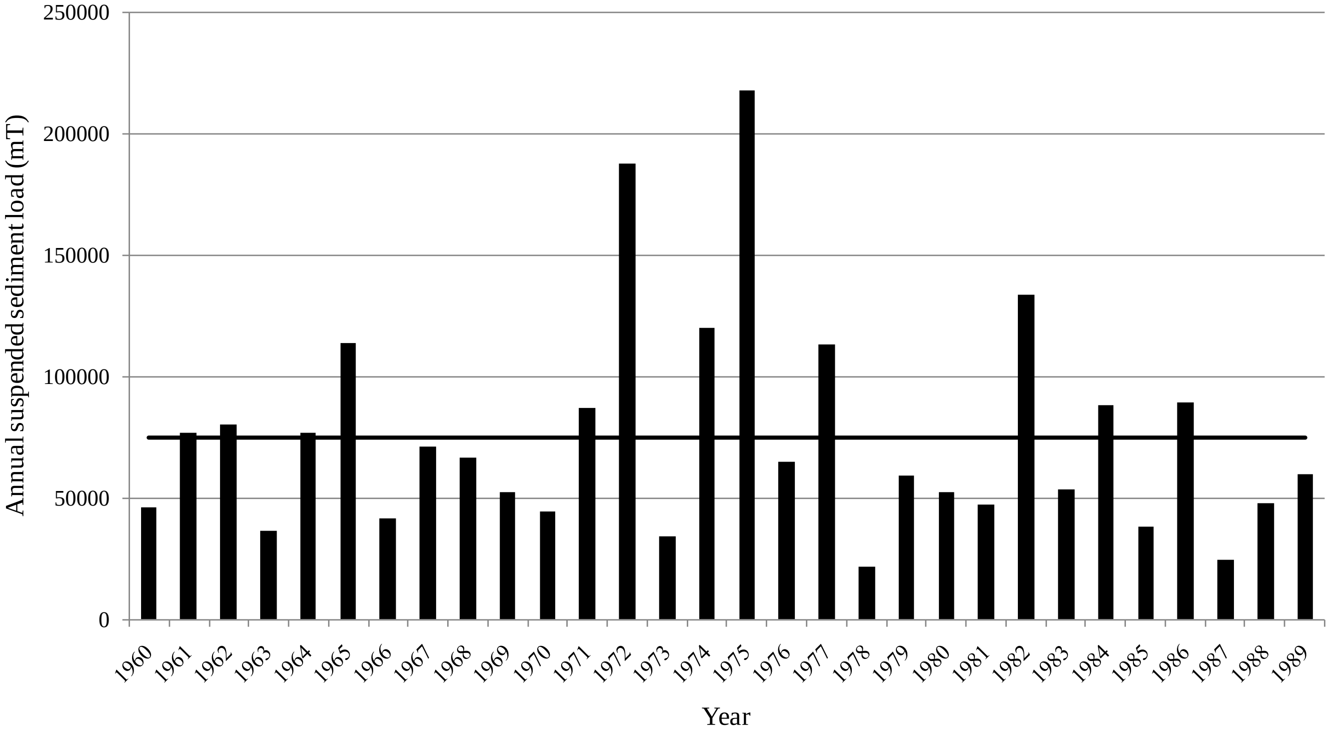

Figure 12. Estimated annual loads of suspended sediment for the Green River at Auburn, 1960-1989.

Contaminant loads

Daily contaminant loading

Daily contaminant loads shown in Table 8 reflect sampling events that targeted a large range of flows and suspended sediment levels. Highest daily loading occurred during November and January when daily flows and sediment loads were greatest but concentrations were low or undetected. Lowest daily loads occurred during one of the low-flow months. However, the daily loads for the organic contaminants measured in August, when daily flows were lowest, were relatively high compared to the maximum measured daily loads.

Table 8. Daily contaminant loads based on results for 7 sampling events.

Contaminant (mass unit/day)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Range (Jul – Jan)
Total PCBs (g/d)	0.07	0.48	0.09	0.14	1.21*	0.06*	0.93*	0.06-1.21
PCDD/F TEQ (mg/d)	-	0.12	0.07	0.04	0.73	0.03	0.64	0.03-0.71
cPAHs TEQ (g/d)	0.49	4.5	0.30	1.3	6.4	1.0	12	0.30-12
Arsenic (kg/d)	0.13	0.17	0.19	0.20	4.47	0.31	7.28	0.13-7.28

* = If a parameter was not detected, then calculations were based on the highest reporting limit (RL) for Total PCBs, and the sum of one-half detection limits (DLs) for PCDD/Fs and cPAHs.

Annual contaminant loading

Estimating annual contaminant loads to the LDW from suspended sediments in the Green River were problematic for several reasons:

- Sediment loading was found to be very episodic during most years. For 8 of 10 randomly-chosen years, 67% of the annual sediment load occurred on the 20 days having the highest daily sediment loads (Figure 13). Episodic sediment loading has been found to be common in other river systems (Baker, 1988, quoted in Richards, 1998).
- The size of the data set was limited to 7 or fewer detected values, precluding the use of multiple regression and other load models to estimate annual loads.[13]
- Regressions between contaminant concentrations and flow may have been fortuitous because they did not represent the rising stage of high sediment load events.

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[13] Multiple regression models yield unreliable predictions when based on fewer than 10 time-series observations of pollutant levels (Pelletier and Roberts, 2009).

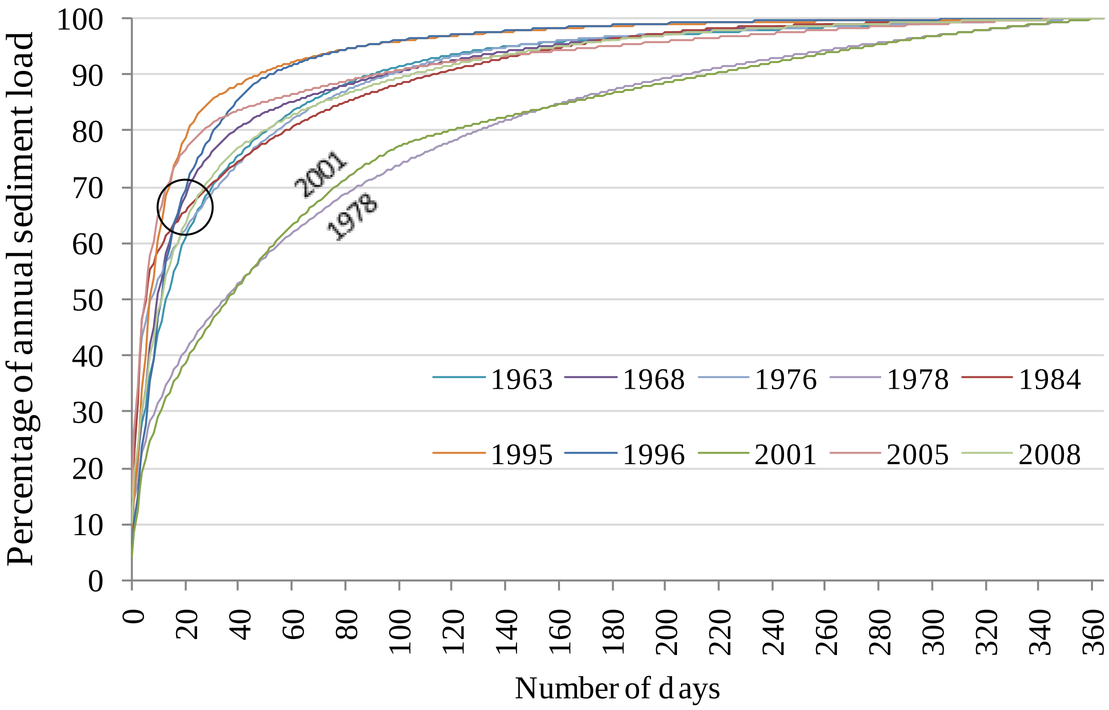

Figure 13. Cumulative frequency distributions for 10 random years of sediment load.

For 8 of 10 years, an average of 67% of the annual sediment load occurred during 20 days (area circled).

Instead of a detailed analysis of annual contaminant loading, scenarios using the regression relationships described were developed to *approximate* lower and upper bounds for annual contaminant loading. Both approximate bounds were based on:

- Mean daily flows recorded at Auburn.
- TSS predicted from mean daily flows (Figure 2).
- Regression equations predicting dry-weight contaminant concentrations in suspended sediments from mean daily flows (Figure 11).

Approximate **lower and upper bounds**

An approximate lower bound for annual contaminant loading used a scenario that assumed contaminant concentrations are always low during high-flow events. This arguably unrealistic assumption enabled use of the regressions described, coupled with mean daily flows at Auburn, to predict daily contaminant concentrations. These were multiplied by the concentration of suspended solids predicted by the USGS rating curve, described earlier, to yield daily contaminant loads that could then be summed (Table F-2). Ecology staff believes that the resulting approximate lower-bound values are likely to be conservative because at least some high-load events likely transport suspended sediments having elevated contaminant concentrations.

An approximate upper bound for annual contaminant loading assumed that contaminant concentrations similar to the ones measured during the August sampling event could represent the first 48 hours (rising stage) of *all* high-flow events during the year (also Table F-2). These assumptions were unrealistic, too. Not all high-flow events will be accompanied by elevated contaminant concentrations, and the absolute concentrations of contaminants will vary. However, the assumptions should produce a conservative upper bound for annual loads.

Table 9 shows the range of concentrations bracketed by these approximate lower- and upper-bound annual loads. It also shows the same values converted to daily sediment concentrations, and annualized sediment- and flow-weighted concentrations. The daily loads derived from the approximate lower- and upper-bound annual loads generally encompassed those actually measured during this study (Table 8). The approximate upper bounds usually exceeded measured daily loads, perhaps because samples did not capture the high events such as those that were likely responsible for the upper-bound values.

Flow-weighted contaminant concentrations based on approximate upper-bound annual loads may not be conservative if the USGS rating curve substantially underestimates the sediment loading.

Table 9. Approximate lower and upper bounds for annual contaminant loading.

Ranges of concentrations shown are the extremes for lower and upper bounds derived from 1960-1989 mean daily flows. Results are also expressed as load-weighted and flow-weighted average contaminant concentrations.

Contaminant	Basis for prediction	Outputs			
		Range of *approximate* lower and upper bound annual loads (dry mass/ yr)	Daily load (annual loads / 365 days) (dry mass/day)	Load-weighted concentration (dry weight)	Flow-weighted concentration
Total PCBs	$y = 28275x^{-1.184}$	155-2270 g	0.42-6.2 g	1.3-23.6 µg/kg	137-1630 pg/L
PCDD/F	$y = 3700x^{-0.991}$	75-680 mg	0.20-1.85 mg	0.8-5.7 ng TEQ/kg	0.08-0.44 pg/L
cPAHs	$y = 110230x^{-1.076}$	1.26-21.5 kg	3.48-58.8 g	12-180 µg TEQ /kg	1.2-14.3 µg/L
Arsenic	$y = 238x^{-0.389}$	320-1,730 kg	0.88-4.75 g	8.0-14.8 mg/kg	0.38-1.0 µg/L

y = dry weight concentration of contaminants associated with suspended sediment.
x = mean daily flow (cfs).

Summary

Contaminant concentrations associated with centrifuged sediment samples (Table 5), measured daily loads (Table 8), and derived from approximate lower and upper bounds for annual loads (Table 9) are most appropriately compared to contaminant concentrations cited in the following 3 studies. [14]

- King County (2009). Total PCBs and cPAHs in suspended sediments were estimated by measuring levels in whole water samples and normalizing results to TSS in the same sample. Arsenic in suspended sediments was calculated as the difference between levels measured in whole and filtered water samples.
- LDWG (2007). Contaminant concentrations were measured in surface sediment samples collected upstream of the LDW during the remedial investigations.
- Longtine (2009). Surface sediment samples were collected upstream of the LDW (RM 4.8-7.0). Sampling locations included mid- and side-channel stations, near outfalls, and areas expected to have high % fines or high % TOC.

Table 10 compares results of these studies. It shows that the mean concentration of total PCBs measured in suspended sediments during this 2008-09 study was substantially lower than the mean value calculated from whole water sample results (King County, 2009). Sampling methods differed but the most likely explanation was the implicit assumption that no PCBs were present in the dissolved or colloidal phase of the water samples. In fact, a substantial fraction of organic contaminants in water samples may exist in these phases (Dangerfield et al., 2007). In contrast, the mean or geometric mean concentration of total PCBs was similar to the mean reported from the latter two studies (LDWG, 2007; Longtine, 2009).

Mean and geometric mean concentrations of PCDD/Fs and arsenic in suspended sediment were significantly greater than comparable values reported for upstream surface sediments ($p<0.01$). This could be explained by larger suspended sediment particles with lower contaminant concentrations being deposited in the upstream channel while more highly-contaminated, finer suspended sediments are transported downstream.

Mean cPAH concentrations measured in suspended sediments and calculated from whole water samples were almost identical. This was contrary to expectations, but some studies have shown PAHs to have had a strong affinity for silt-sized particles (Krauss and Wilcke, 2002; Müller et al., 2000; Umlauf and Bierl, 1987), perhaps such as the silts common in the Green River. The geometric mean for cPAHs was equal to or greater than bedded sediment cPAHs. This could also be explained by the winnowing process described for PCDD/Fs and arsenic.

Finally, Table 10 shows that the mean arsenic concentration measured in suspended sediments was also lower than in King County samples. Reasons for this difference were not as obvious. One explanation was that centrifuge samples may not accurately capture colloidal arsenic that can be observed with abundant DOC (Bauer and Blodau, 2009).

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[14] Other related studies were not considered similar enough to this one with respect to purpose, contaminant sources, sampling location, or matrix to warrant comparison.

Table 10. Contaminant concentrations associated with suspended Green River sediments (this 2008-09 study) compared to other relevant studies.

Contaminant (dry weight basis)		Samples collected upstream of LDW site					*Preliminary values* proposed as Green River inputs to Bed Composition Model [5]
		Measured in suspended sediment [1]	From *approximate* lower- and upper-bound annual loads [1] (See Table 9)	*Calculated* from whole water measurements [2]	Measured, upstream surface sediments (Ecology, 2009) [3]	Measured, upstream surface sediments (LDWG, 2007) [4]	
Fines (%)	Min	79.2	-	-	0.0	0.0	-
	Mean	86.0	-	-	11.5	11.7	
	90%	93.1	-	-	52.9	43.6	
	Max	93.7	-	-	79.9	42.4	
TOC (%)	Min	1.72	-	-	0.13	0.07	-
	Mean	4.32	-	-	1.19	0.81	
	90%	5.7	-	-	2.98	1.88	
	Max	6.16	-	-	5.38	2.31	
PCBs (µg/kg)	Min	1.2 U	1.3	2.8	2.3	0.6	50
	Mean	14.5 (6.1)	-	49	7.0	18.0	
	90%	34.3	-	123	11.0	46.0	
	Max	62.1 J	23.6	162.4	22.0	140	
PCDD/Fs (ng TEQ/kg)	Min	0.83	0.8	-	0.07	1.10	5
	Mean	6.36 (3.22)	-	-	0.48	1.15	
	90%	15.3	-	-	1.58	1.19	
	Max	16.2 M	5.7	-	2.25	1.20	
cPAHs (µg TEQ/kg)	Min	13.1 J	12	22 U	0.9	9.0	170
	Mean	143.5 (57.5)	-	140	19.3	51.0	
	90%	372	-	340	57.8	250	
	Max	588	180	408	235	64.4	

Table 10 continued.

Contaminant (dry weight basis)		Samples collected upstream of LDW site					*Preliminary values* proposed as Green River inputs to Bed Composition Model [5]
		Measured in suspended sediment [1]	*Estimated* from annual loads [1] (See Table 9)	*Calculated* from whole water measurements [2]	Measured, upstream surface sediments (Ecology, 2009) [3]	Measured, upstream surface sediments (LDWG, 2007) [4]	
Arsenic (mg/kg)	Min	9.2	8.0	0.5	3.7	3.3	10
	Mean	16.6 (15.4) Fines 15.7 Sands 6.3	-	37	6.0	7.0	
	90%	23.9	-	76	9.1	11.0	
	Max	24.3	14.8	133	15.0	22.0	

J = estimated value, U = not detected at the level shown, M = mean of duplicate measurements.
Values in parentheses are geometric means; 90% = 90th percentile value.

[1] From results for centrifuged samples (this study) except as noted for arsenic.

[2] King County, 2009, as presented in LDWG, 2009. Organic contaminants were measured in samples of whole surface water and normalized to the TSS content of each sample (n = 22 for Total PCBs; n = 18 for cPAH). Arsenic values are whole-water results less filtered-water results (n = 100).

[3] Longtine, 2009. 51 surface sediment samples were collected in July 2008 from various upstream locations between RM 4.8 – 7.0. Samples were collected mid-channel, at bench locations, and near stormwater outfalls.

[4] LDWG, 2007. n= 34 for Total PCBs, n = 2 for PCDD/F, n = 13 for cPAHs, and n = 13 for arsenic.

[5] LDWG, 2009.

This 2008-2009 study provides the first direct measurements of contaminant concentrations associated with suspended sediments in the Green River. There is still uncertainty about how well the samples collected and analyzed represent suspended sediments entering the LDW. But the samples almost certainly represent in-situ suspended sediments more accurately than periodic surface-water grab samples or bedded sediment samples. As such, study results comprise a strong line of evidence for future contaminant inputs to the LDW.

The results, when considered with those from the 3 other studies evaluating contaminant concentrations in upstream sources, appear to support input values to a bed composition model (BCM) that fall in the following ranges:

- Total PCBs ~ 5-20 µg/kg (approximate geometric mean of concentrations measured in suspended sediments to near the *approximate* upper-bound concentration for annual loads).
- PCDD/Fs < 5 ng TEQ/kg (geometric mean of measured values and mid-range of concentrations based on approximate lower- and upper-bound loads).
- cPAHs ~ 50-150 µg TEQ/kg (concentrations near the mean or geometric mean from 2 studies to near the mean values from 2 other studies and the concentration calculated from *approximate* upper bound annual loads).
- Arsenic ~ 15 mg/kg (concentration near the mean arsenic measured in fine suspended sediments most likely to be transported into the LDW).

The BCM does not currently distinguish between contaminant levels associated with different size classes of suspended sediment. Total concentrations are assigned equally to all particle sizes. However, results of this study generally support an approach that would assign greater concentrations to fine-sized suspended sediments. The evidence is most compelling for arsenic. Because of this, segregation of contaminant inputs associated with the fraction of fine suspended sediments should be evaluated further in the BCM. The importance of TOC to contaminant inputs may also need to be considered in the BCM.

Notably, the August sampling event provided evidence that an intense local storm, even if short-lived, influenced total PCBs and other organic contaminants associated with suspended sediments. The stormwater discharges witnessed caused turbidity, and otherwise influenced suspended sediments, for no more than 6 hours of the 47-hour sampling event. For the final centrifuged sediment sample to contain 62.1 µg/kg PCBs, the stormwater would have had to contain approximately 500-1000 µg PCBs/kg dry weight of sediment. This range was similar to the range reported for stormwater cited by the City of Seattle (Seattle Public Utilities, 2009).

This observation raises the question of whether all or just some high-flow events carry similar contaminant loads. Would equal precipitation from a storm occurring only in the upper watershed cause mobilization of similar contaminated suspended sediment? Would high flows from a dam release during the winter contain elevated contaminant concentrations? What portion of each high-flow event would contain high concentrations of suspended sediment, what portion of the suspended sediments would have elevated concentrations of priority contaminants, and what concentrations would be expected?

Without at least qualitative answers to these questions, estimates of mean annual loads will remain speculative.

Uncertainty

This section attempts to identify major and other notable sources of uncertainty without quantifying them. There is little to gain by quantifying some sources of uncertainty if other major uncertainties cannot be quantified.

One of the greatest sources of uncertainty about concentrations of contaminants associated with suspended sediments and consequent contaminant loading is the lack of sample results for key periods of high flow and sediment load:

1. Increased flows with antecedent dry periods (summer or fall).
2. Early phases (rising stage) of high-flow events.
3. Increasing discharges resulting from local storm events.

It is potentially problematic to develop estimates of mean annual contaminant loading when the calculations rely on daily sediment loads and contaminant concentrations that are both predicted from mean daily flow. This is further confounded by the episodic nature of sediment loading. Very little is known about contaminant loading during infrequent high-flow events that account for nearly all the annual contaminant load. Finally, assigning high contaminant concentrations, influenced with a single local storm event, to suspended sediments for speculative periods is not justified other than to *approximate* an upper bound on annual loads.

Another source of uncertainty relates to the accuracy of the sediment rating curve. The 2-fold difference between estimates of annual sediment load (this study and the STM) may be common for many river systems, but annual sediment load could have a profound influence on choice and efficacy of cleanup alternatives.

The issue of just how representative pump sampling suspended sediment is, and how representative the contaminant concentrations measured in centrifuged samples are, remains uncertain. Much of the uncertainty was expected, and could not be avoided, when the clear priority was to periodically collect enough suspended sediment to enable direct analysis of contaminants. Ecology staff believes that the advantages to the field methods chosen outweighed the disadvantages.

Most other sources of uncertainty (specific field sampling methods and representativeness of samples, analytical accuracy, and precision) are relatively minor.

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Conclusions

The purpose of this 2008-09 study was to estimate the suspended sediment loads for the highest priority chemicals of concern in Lower Duwamish Waterway (LDW) cleanup efforts. This involved measuring levels of Total PCBs, PCDD/Fs, cPAHs, and arsenic associated with suspended sediments from the Green River.

General

- The field approaches to collecting samples of suspended sediment and the laboratory methods to measure contaminants in them were generally effective.
    - Time-integrated samples (24-48 hours continuous pumping) and, to a lesser extent, depth-integrated samples (single target depth but stage heights changing with tides) were collected over a range of environmental conditions.
    - Continuous-flow centrifugation and field sieving efficiently removed suspended sediments from river water, usually providing enough mass for the priority analyses.
    - Field and laboratory measurements showed samples were substantially representative of suspended sediments present in the central channel of the Green River.
    - Additional measurements of suspended particle distributions in the water column, and side-by-side depth-integrated water samples, would have aided the evaluation of representativeness.
    - A major data gap and source of uncertainty was that suspended sediment was not collected during the rising stage of a major flow event.
- Study results provide an independent line of evidence for contaminant concentrations that may enter the LDW from the Green River. The results should be strongly considered when developing final input values to models that predict post-cleanup surface sediment quality.

Suspended sediment contaminant levels

- Measured levels of organic contaminants varied with the season, mean daily flow, storm-related discharges, and phase of high-flow events.
- Organic contaminant concentrations measured in suspended Green River sediments fall within the following ranges (dry-weight):
    - Total PCBs – 1.2 - 62.1 µg/kg dry sediment.
    - PCDD/Fs – 0.83 - 16.2 ng TEQ/kg dry sediment.
    - cPAHs – 13.1 - 588 µg TEQ/kg dry sediment.
- Maximum organic contaminant concentrations occurred in centrifuged sediment samples collected during August and were more than 10 times the minimum concentrations measured in samples collected during the falling stage of high-flow events (November 2008 and

January 2009). August sample results were influenced by the turbidity visible following stormwater discharges observed early in the course of that sampling event.

- Arsenic concentrations measured in suspended sediment were not as variable (9.2 - 24.3 mg/kg).
- Arithmetic or geometric mean contaminant levels for centrifuged sediment samples were similar to or greater than those measured in bedded sediments upstream of the LDW, suggesting a settling or winnowing of less contaminated particles.
- Mean contaminant levels were often less than values calculated from results of water samples assuming all contaminants were associated with suspended sediments (King County, 2009). This observation suggested contaminants may also be present in dissolved or colloidal forms.

Contaminants by size fraction

- Results were generally consistent with the theory and findings of other studies because:
  - Arsenic concentrations in sand-sized suspended sediments were always less than levels calculated for the finer suspended sediment fractions.
  - Organic contaminant levels usually followed the same pattern.
  - Organic contaminant levels measured in July and August samples may have been associated with the relatively high carbon content of sand-sized suspended sediments. August samples, in particular, may have contained high-carbon terrestrial material and organic contaminants derived from the local stormwater discharges that were observed.

Loading estimates

- Sediment loading in the Green River was found to be highly episodic in nature. Two-thirds of the annual sediment load was delivered to the LDW during just 20 days.
- A mean annual load of suspended sediment of 74,800 metric tons was estimated using mean daily flows for the period 1960-1989 and a rating curve based on 1996-1998 data. This estimate was 48% of the annual suspended sediment load reported in the sediment transport model (STM; 157,000 mT). The lower estimate was likely due to:
  - Use of USGS data from 1996-1998 only.
  - Applying a single rating curve, based only on these data, to all levels of flow.
  - Not adjusting the rating curve to calibrate the STM.
- Estimates of annual contaminant loading associated with suspended Green River sediment were difficult because:
  - Annual sediment loading was episodic.
  - A much better understanding was needed of the contaminant concentrations associated with sediment suspended during all phases, but especially the rising stage, of diverse high-flow events.

- Estimates of annual contaminant loading will be sensitive to assumptions made about:
    - The number of high-flow or high sediment-load events that carry suspended sediments containing elevated contaminant levels.
    - The temporal pattern of contaminant concentrations associated with suspended sediments over the progression of each high-flow event.

Recommendations

Estimates of sediment and contaminant loading should be improved to reduce the uncertainty associated with future contaminant loading to the LDW site. Therefore, the following recommendations are made:

1. Results of this study should be used as a strong additional line of evidence for choosing suitable contaminant levels as inputs to the bed composition model.

2. Develop more accurate estimates of annual contaminant loads (and weighted mean annual contaminant concentrations) associated with suspended Green River sediments. Additional sampling and analysis should be conducted to provide a better understanding of temporal patterns of sediment-bound contaminants that are mobilized during all types of high-flow, high-sediment load events.

   The study design would need to feature frequent sampling intervals. Multiple pumps and continuous-flow centrifuges could be deployed to this end, but substantially greater field resources would be required and representativeness of samples could still be questioned.

   It appears there is more uncertainty associated with the episodic nature of suspended sediment contaminant loading than about the difference in concentrations between results for water and centrifuged sediment samples. Therefore, an appropriate alternative to the use of continuous-flow centrifuges would be to collect frequent whole water samples using automated samplers (King County, 2007). Multiple ISSCO-type automated samplers would be triggered to collect water samples at 2-hour intervals by a rising stage and increased turbidity. Samples would be analyzed for PCB congeners with EPA Method 1668A and perhaps additional contaminants. Results, when normalized to suspended sediments concentrations (SSC) (see King County, 2009), may overestimate contaminant concentrations associated with suspended sediment, but would greatly improve estimates of contaminant loading associated with suspended sediments.

3. Future nutrient or contaminant loading studies, especially where the majority of the annual sediment load occurs episodically, should consider the potential importance of measuring SSC and not total suspended solids (TSS).

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

ADCP: Acoustic Doppler current profiler – an instrument that measures current velocities throughout a natural or artificial channel and is often used to estimate total discharge or flow.

Bed load: Sediment particles that are transported by rolling, sliding, traction, and saltation along the river bottom (bed).

Colloids, colloidal phase: Particles that remain evenly distributed throughout another substance without settling out. Colloids are intermediate in size (0.01 – 1.0 µm) between ones in solution (dissolved) and ones that are suspended but will eventually settle out. The mixture formed by colloids is called a colloidal dispersion or colloidal phase.

Detection limit: Lowest quantity of a parameter that can be distinguished from the absence of that substance within a stated confidence limit (generally 1%). The detection limit is estimated from mean, standard deviation, and some confidence interval for a blank sample.

Efficiency: For this study, the efficiency of continuous-flow centrifuges at retaining suspended solids. This is calculated as: 1 - (TSS in centrifuge effluent/TSS in centrifuge influent).

Geometric mean: Mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of individual values.

Grab sample: A discrete sample from a single point in the water column or sediment surface.

Load(ing): The mass a substance (suspended sediment or contaminant) passing by a horizontal or vertical plane per unit time. For example, the metric tons of sediment calculated to be transported downstream of a particular location.

Nth Percentile: A value in a distribution of a data below which N% of the data exists and above which (100-N)% of the data exists. The 90th percentile is the value in a distribution of data below which 90% of the data exists and above which 10% of the data exists.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Rating curve: The relationship between log-transformed concentration (or flux) and flow.

Reach: A specific portion or segment of a stream or river.

Reporting limit: The lowest quantity of a parameter that can be determined with stated, acceptable precision and accuracy under stated analytical conditions (e.g., lower limit of quantitation). The reporting limit is often three times the method detection limit (or greater).

Salt wedge: A salt wedge estuary exhibits limited mixing of salt and fresh waters. Salt water forms a wedge that is thickest at the estuary mouth and becomes thinner as it proceeds landward. Penetration of the salt wedge changes with the river flows, with retreat during high flows and greater penetration during low flows.

Stage: The level of the water surface in a river (gage height) relative to some stated vertical datum.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

TEF: Toxic equivalency factors are toxicity potency factors used by the World Health Organization (WHO), scientists, and regulators to evaluate the overall toxicity of highly variable mixtures.

TEQ: Toxic equivalents is a toxicity-weighted total mass of a substance or family of substances. Total TEQ is calculated as the sum of products of the measured mass times the appropriate potency (TEF) for all compounds in a family of compounds.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

ADCP	Acoustic doppler current profiler
BCM	Bed composition model
CI	Confidence interval
cPAHs	Carcinogenic PAHs
DL	Detection limit
DMMP	Dredged Material Management Program
DOC	Dissolved organic carbon
Dup.	Sample duplicate
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LISST	Laser in situ scattering and transmissometer
MEL	Manchester Environmental Laboratory
MTCA	Model Toxics Control Act
n	Number of Samples

NPDES	National Pollutant Discharge Elimination System
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCDD/F	Polychlorinated dibenzo-p-dioxins and –furans
POC	Particulate organic carbon
PRL	Pacific Rim Laboratories
QA	Quality assurance
QC	Quality control
RL	Reporting limit
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SMS	Sediment Management Standards
SRM	Standard reference materials
SSC	Suspended sediment concentration
STM	Sediment transport model
TCDD	Tetrachlorodibenzo-p-dioxin
TEF	Toxicity equivalent factor
TEQ	Toxic equivalent
TOC	Total organic carbon
TSS	Total suspended solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code

Units of Measurements

°C	degrees centigrade
°F	degrees Fahrenheit
cfs	cubic feet per second, a unit of flow
cms	cubic meters per second, a unit of flow
dw	dry weight
fps	feet per second
ft	feet
g	gram, a unit of mass
g/d	grams per day
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters

l/d	liters per day
m	meter
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
mT	metric tons
oz	ounce
ng/Kg	nanograms per kilogram (parts per trillion)
ppT	parts per thousand
µg/kg	micrograms per kilogram (parts per billion)
µm	micrometer
ww	wet weight

Appendix B. Field Sampling Photographs and Notes

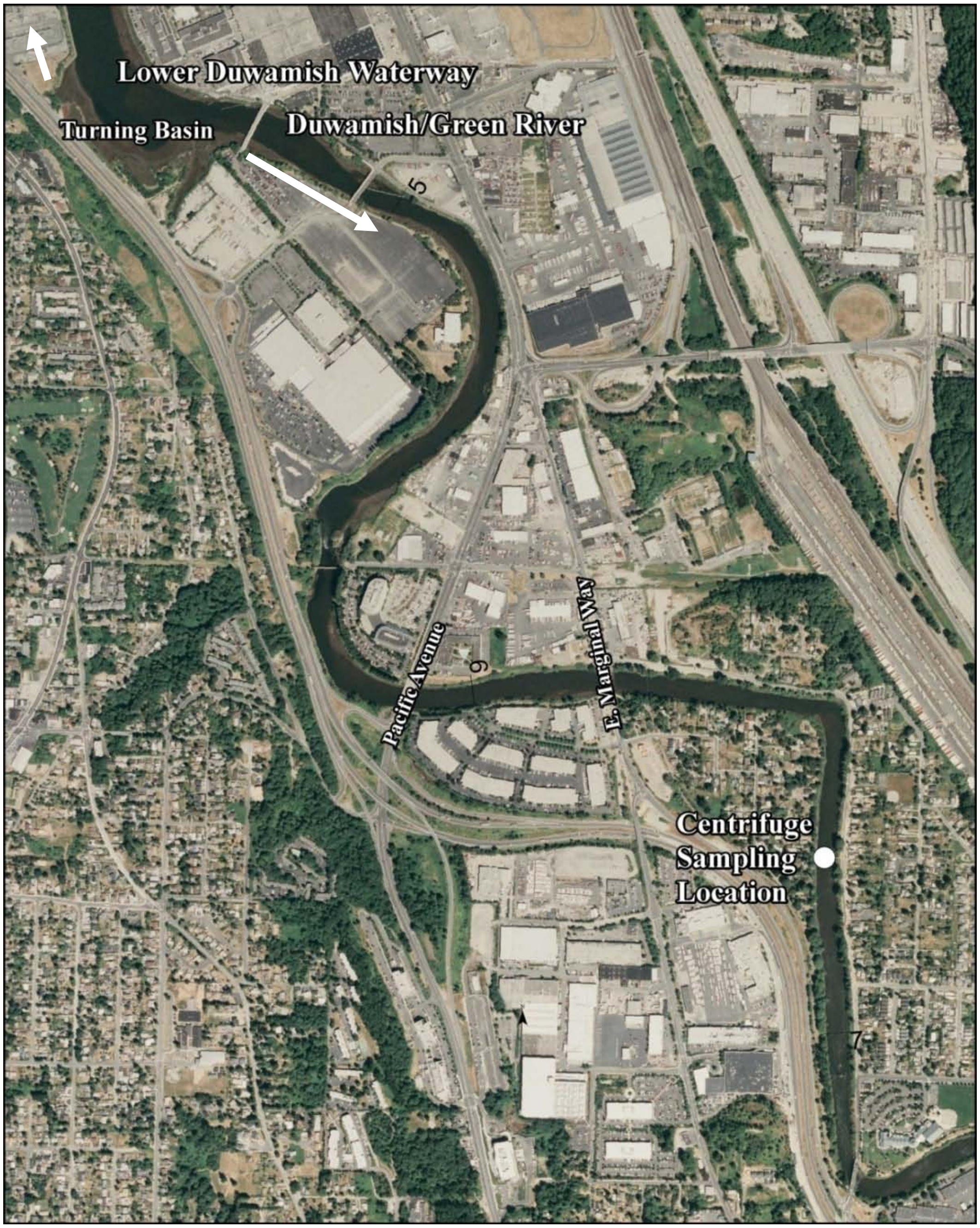

Figure B-1. Study site from the upstream turning basin (near the south boundary of the Lower Duwamish Waterway cleanup site) to approximately River Mile 6.8 where suspended river sediments were collected (119th Street footbridge).

Figure B-2. 119th Street footbridge crossing the Lower Duwamish/Green River at approximately River Mile 6.7 where suspended sediments were collected.

Note staff gage on nearest bridge support and buoy-marked Teflon tubing leading from submerged pump up to bridge deck.

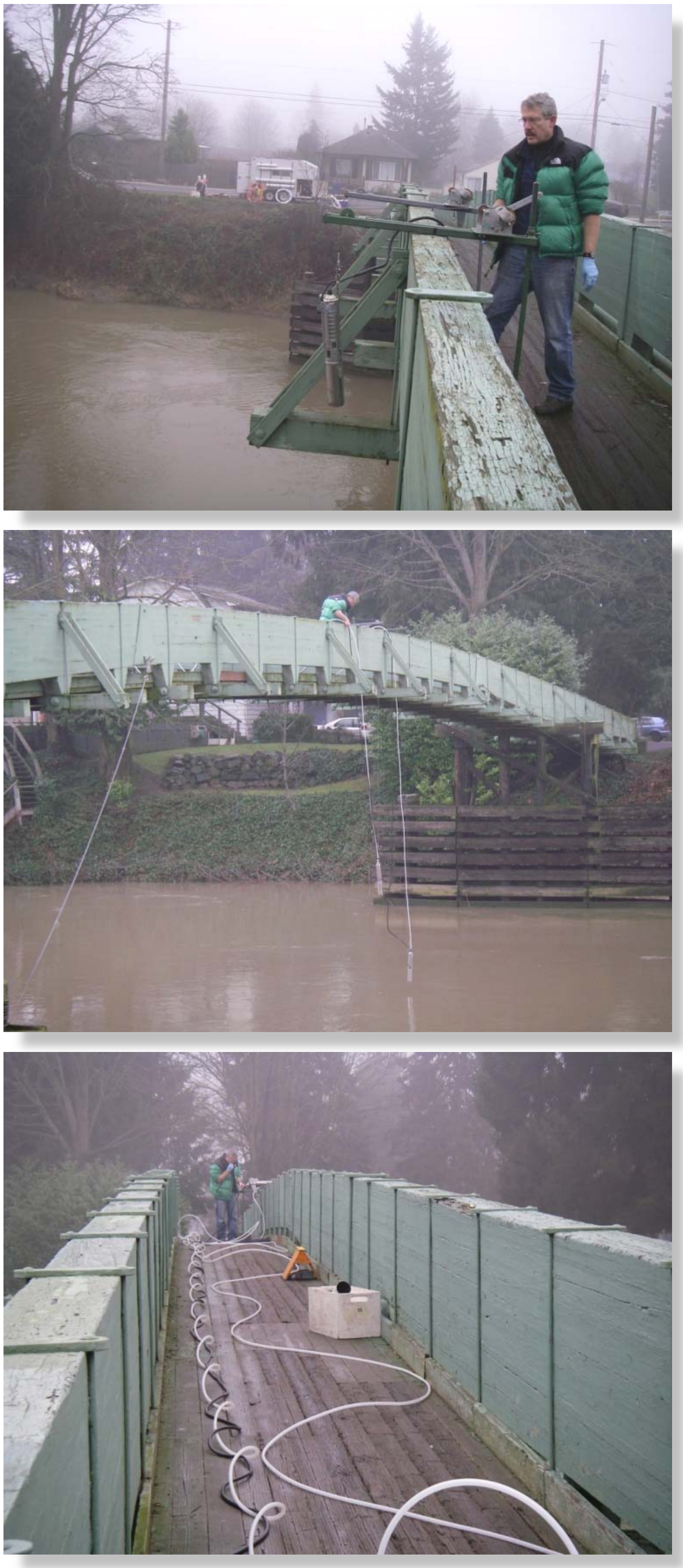

Figure B-3. Top - bridge boards used to lower and maintain position of pump. Middle - deploying a second pump into central channel. Bottom - running Teflon-lined tubing that will convey pumped river water along the bridge deck to the centrifuge trailer and sieving stations.

Figure B-4. Interior of trailer housing 2 Alpha Laval continuous flow-through centrifuges with influent flow controls.

The tube conveying pumped river water enters the trailer at the lower right. Flow is split and regulated by means of ball valves (blue levers in upper right). Flow to the two centrifuges is equalized, and the rate is approximated using the two amber-colored float gages. Regulated influent enters the tops of the centrifuges via nearly horizontal tubes. Effluent from the centrifuges can be sampled as it leaves the trailer through the larger diameter tubing, also at the lower right.

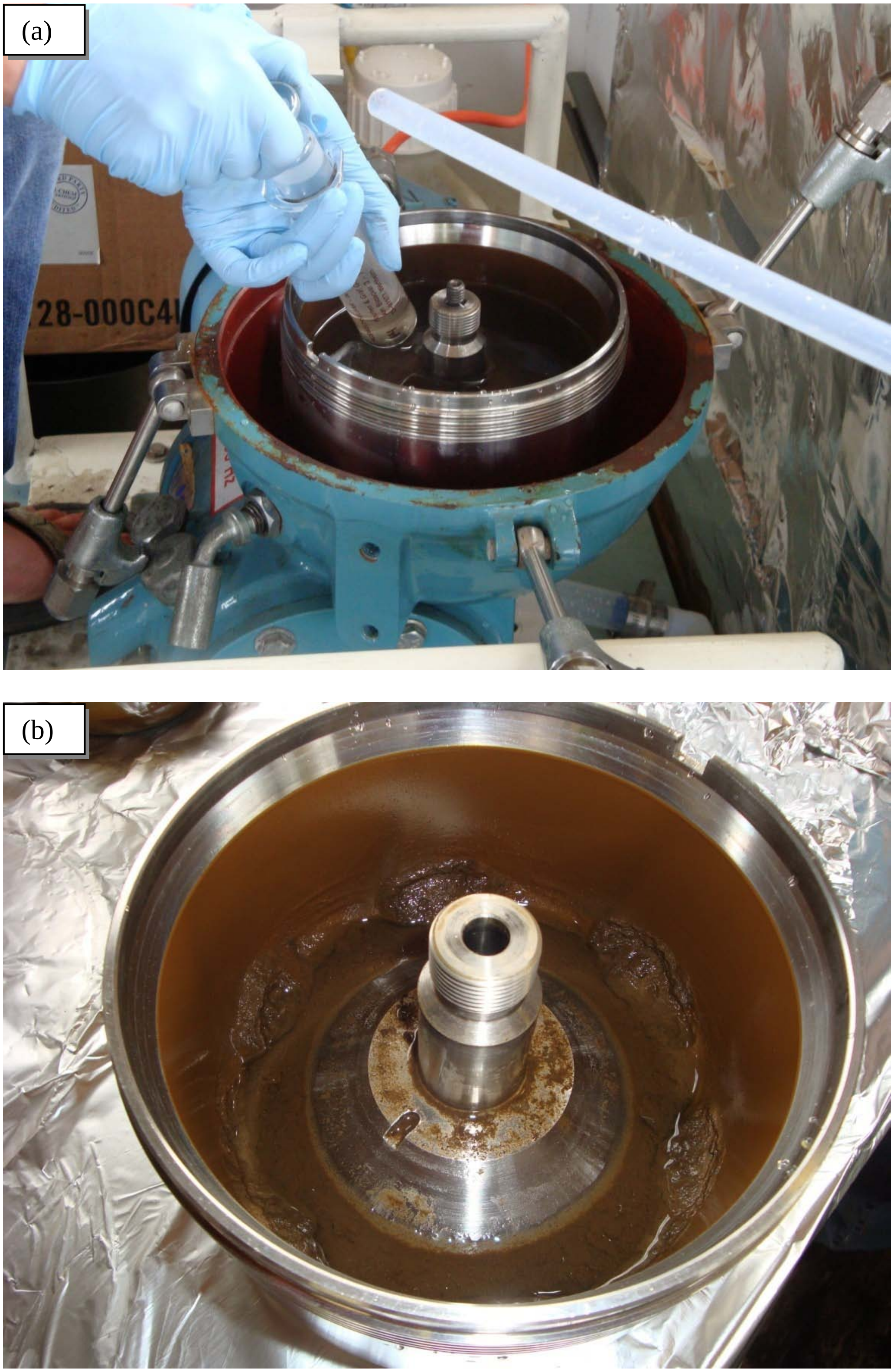

Figure B-5. (a) Removing excess water from centrifuge bowl, and (b) view of the retained suspended sediments.

Figure B-6. Sieving station at end of sampling site footbridge.

River water in Teflon-lined tubing enters closed 5-gallon buckets and passes through sieves. Effluent drains through green garden hoses. Flow rate is measured as the stop-watch time needed to fill a container of known volume.

Figure B-7. Rinsing sieves to collect coarser (sand) fraction of suspended sediments.

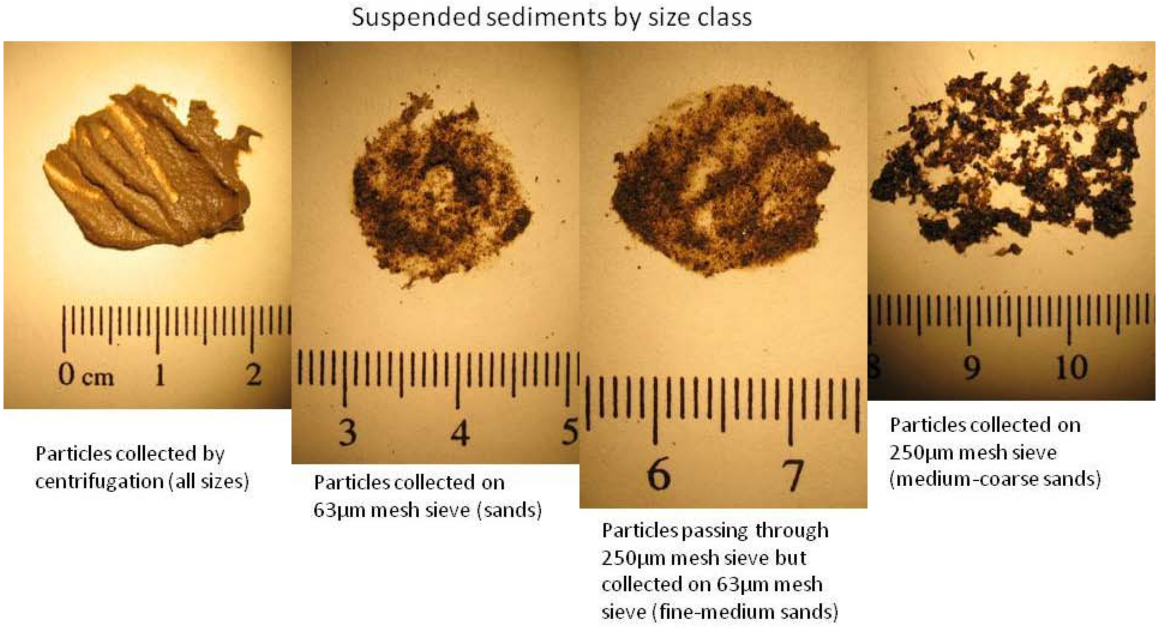

Figure B-8. Suspended sediments by size class.

Material collected by the centrifuges, representing particles of all sizes, is shown in the photograph on the left. The next 3 photographs show material collected by a single sieve or by stacked sieves. These represent different size ranges of suspended sediments.

Appendix C. Database Design

Ecology's EIM database contains laboratory results for all water and sediment samples that were collected for this study. The EIM User Study ID is LDW_08.

EIM does not contain the field measurements made and notes taken during the sampling events. These are available in a Microsoft Access relational database. The database, which does not contain conventionals or contaminant chemistry results, is available upon request.

Database tables include:

- Event - describes each sampling event.
- Pump - pump intake depth and maximum depth measurements recorded when pump height was checked or changed.
- Centrifuge - start/stop times and flow rates for influent to centrifuges.
- Sieve A/B - start/stop times and flow rates influents to sieves.
- Water - sampling times and volumes associated with water samples.
- Samples - describes each sample.
- Air dried - air dried weights of centrifuged and sieved sediment samples.
- ADCP - start/stop times and StreamPro current profiler current and discharge data.
- Conductivity - specific conductivity and salinity measurements.
- LISST - laser particle size analyzer position and intake depth.

Appendix D. Field Measurements

Figure D-1. Stage and predicted tide heights for 7 sampling events (July 2008 – January 2009).

Figure D-2. Summary of flow measurements for 5 sampling events.

Figure D-3a-e. Examples of current profiles measured during different tidal phases.

Figure D-4. Comparison of current velocity near pump intake to mean velocity in the channel overall.

Figure D-5a-d. Salinity profiles for the Green River at Tukwila measured July – October 2008.

Figure D-6. Pump intake position relative to maximum mid-channel depth.

Figure D-7. Example of time-series measurements of in-situ suspended sediment.

Figure D-8. Particle size distribution for material not retained by centrifuges.

Figure D-9. Particle size distributions for subsamples of sieved sediments resuspended in water.

Stage height

A staff gage was installed on the 119th Street footbridge. Stage height (water level) was read from the staff gage when sieves were cleaned, pump height was changed, ADCP measurements began and ended, conductivity measurements began and ended, and centrifuges were checked.

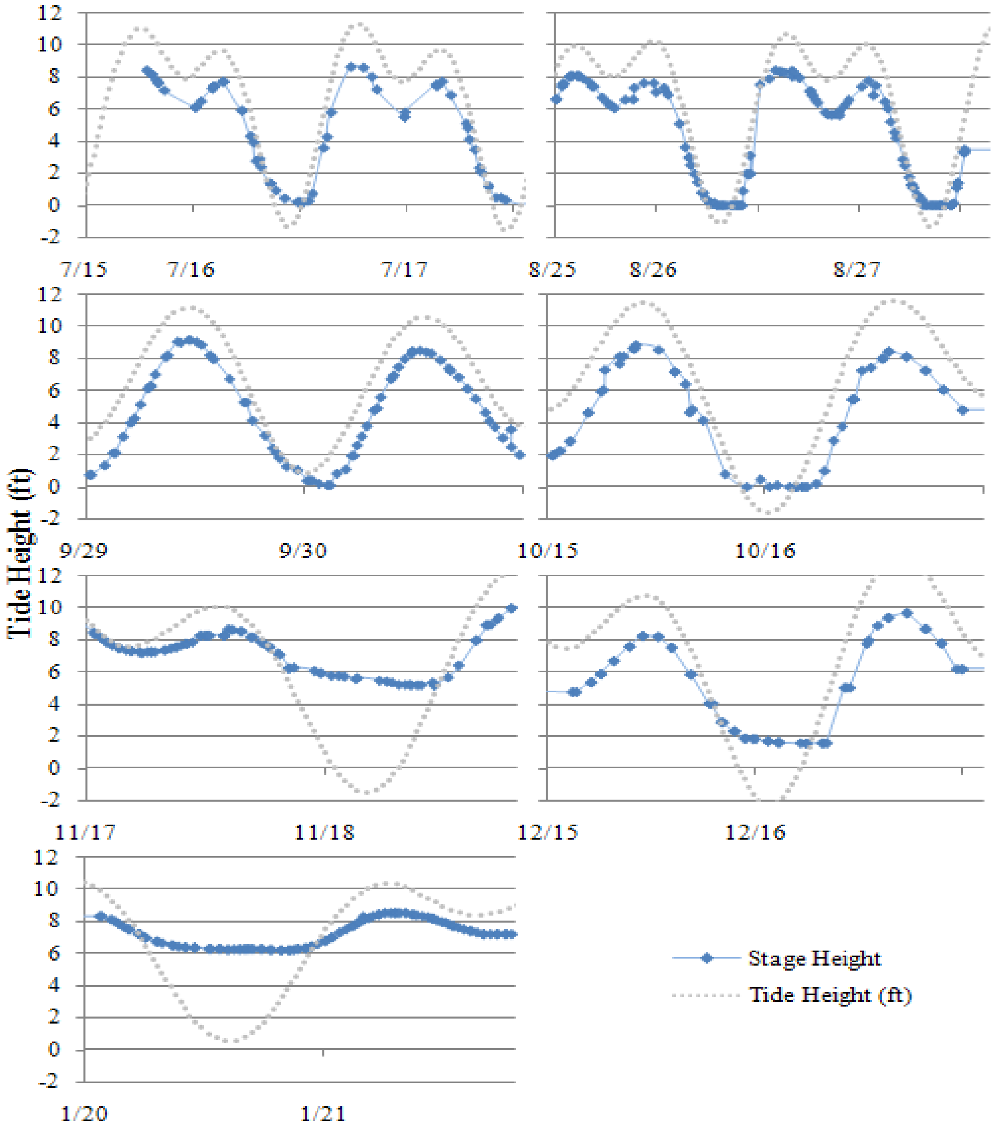

Figure D-1. Stage and predicted tide heights for 7 sampling events (July 2008 - January 2009).

Predicted tide heights are for the Lower Duwamish Waterway at 8th Avenue South (www.co-ops.nos.noaa.gov/tide_pred.html).

Current velocity and flow

A Teledyne/RDI StreamPro acoustic doppler current profiler (ADCP) was used to measure current velocity and estimate flow in the channel at the study site. This was done to better understand and document field conditions while sampling suspended river sediments.

The July - October 2008 sampling events were characterized by relatively low mean daily flow (<1,000 cfs). Mean daily flows for the November 2008 and January 2009 sampling events were 4,000 - 5,000 cfs, following near-flood stage discharges from the Howard Hanson Dam. The StreamPro was not available for the September and December sampling events.

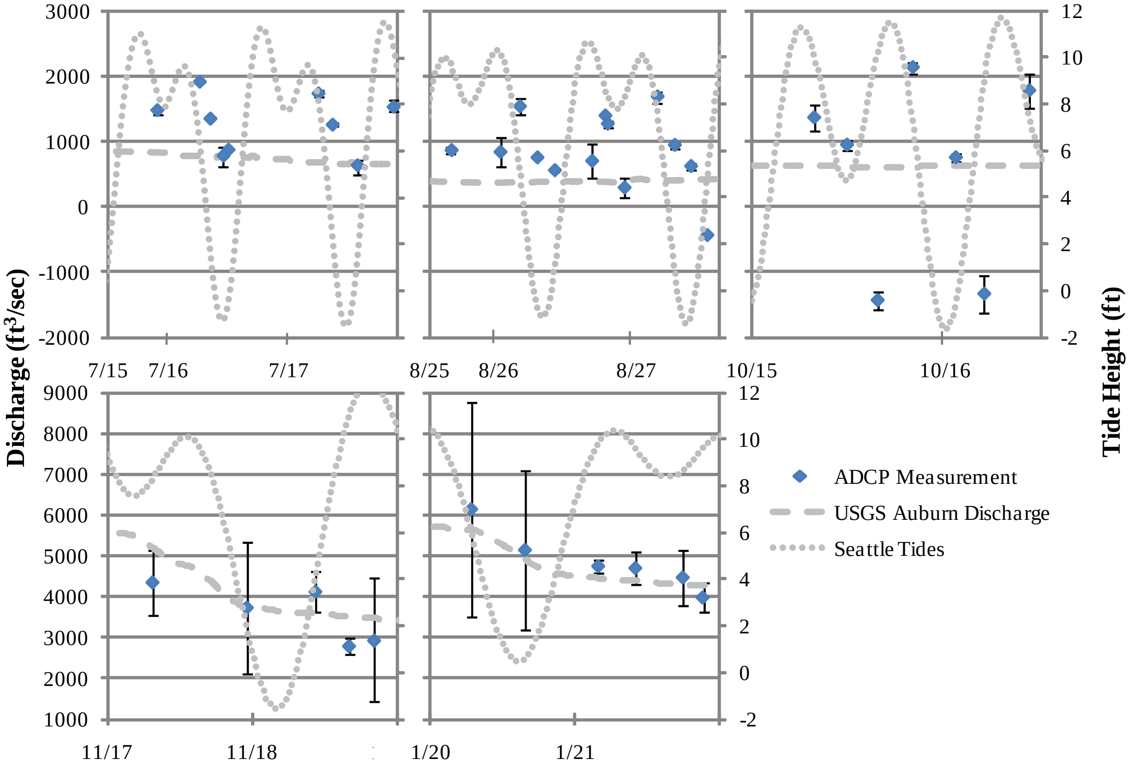

Figure D-2. Summary of flow measurements for 5 sampling events.

Vertical bars represent ± 1 standard deviation of the mean of 3-5 transects that usually required 30 minutes or less to complete. Predicted tide heights are for the Lower Duwamish Waterway at 8th Avenue South (www.co-ops.nos.noaa.gov/tide_pred.html).

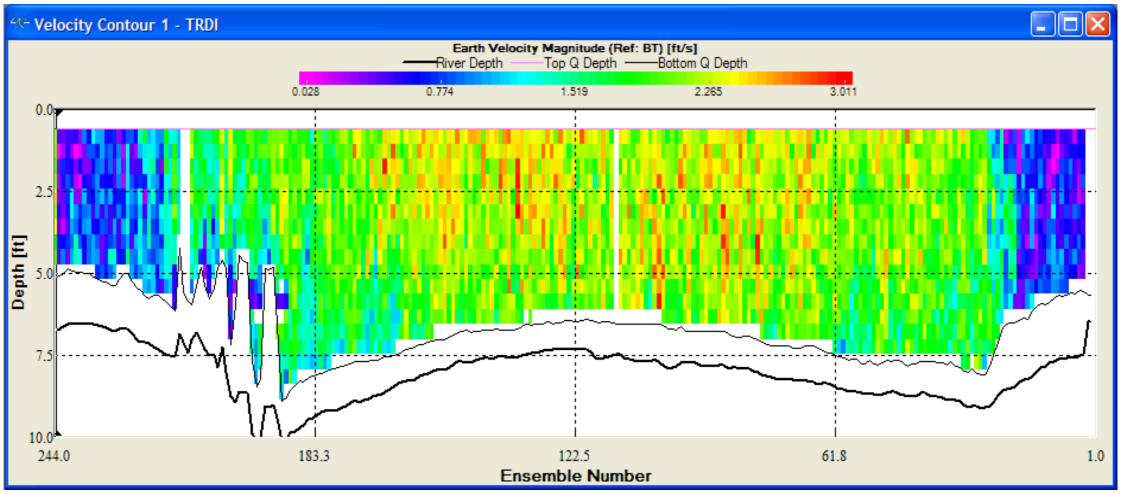

Figure D-3a. Example of ebb tide current profile measured on July 16, 2008 at 06:08.

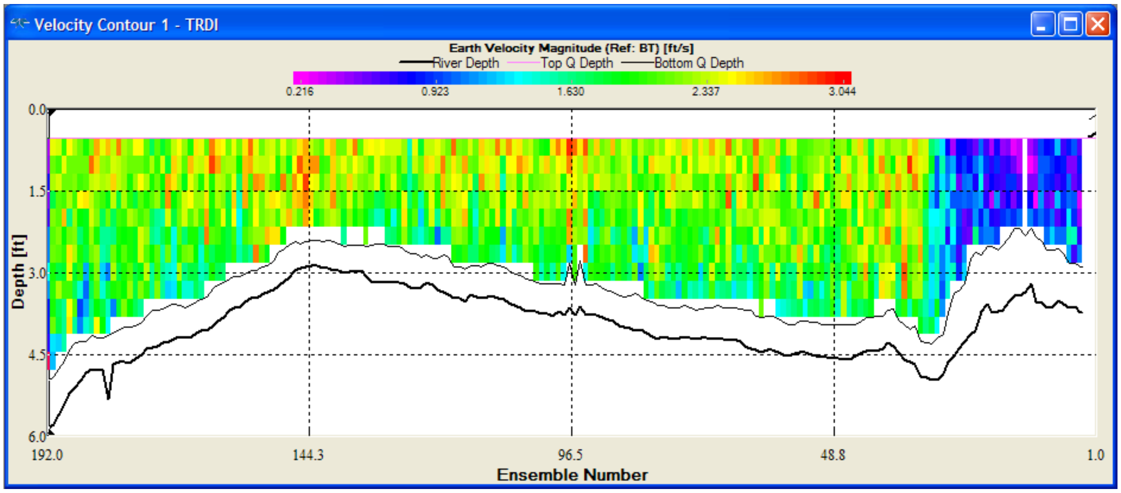

Figure D-3b. Example of low tide flow current profile measured on July 16, 2008 at 10:52.

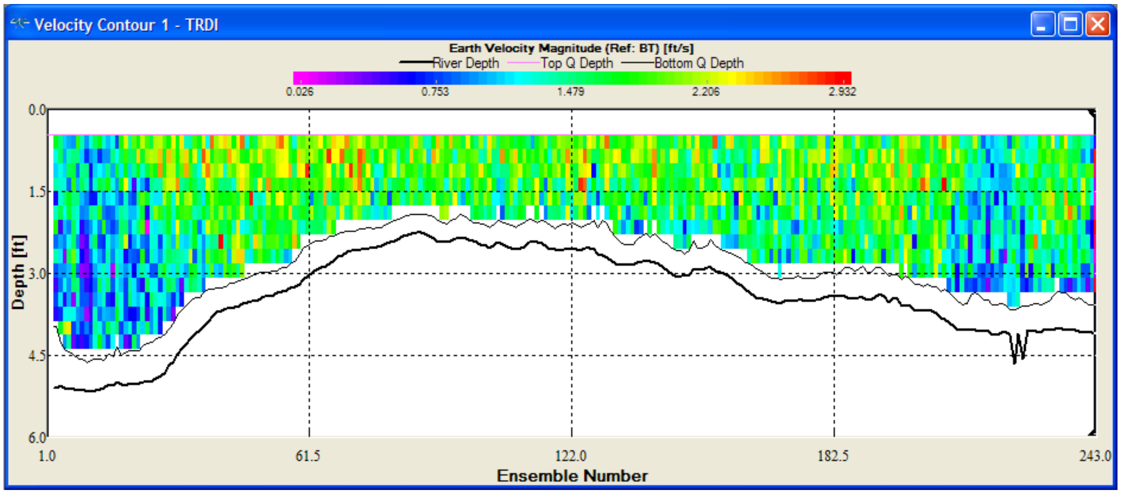

Figure D-3c. Example of flood tide flow current profile measured on August 26, 2008 at 09:40.

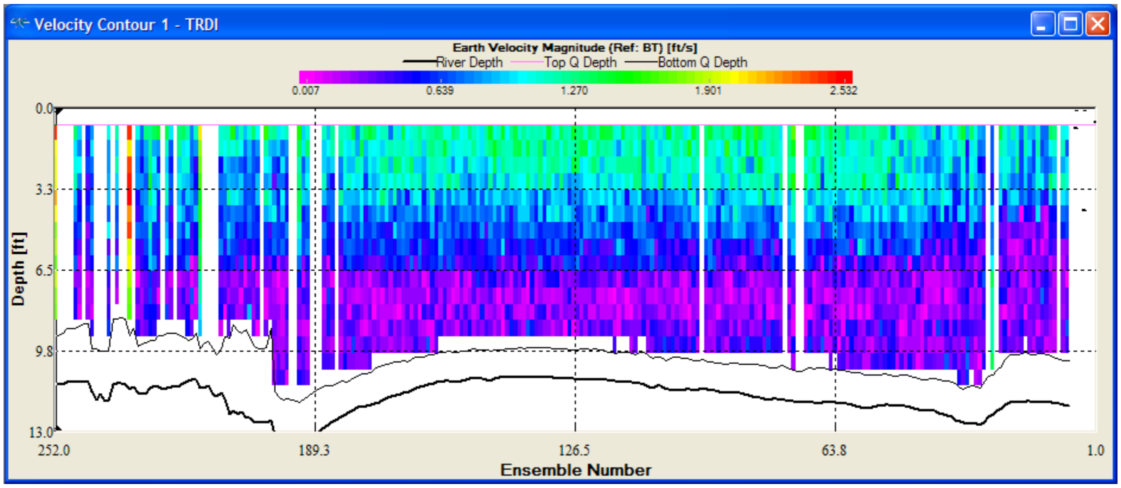

Figure D-3d. Example of high tide flow current profile measured on August 26, 2008 at 16:26.

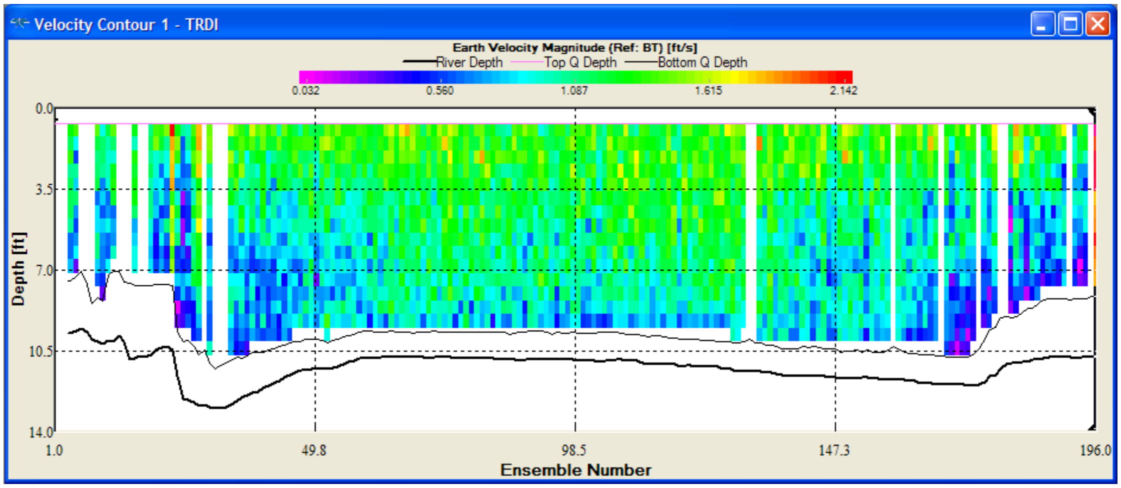

Figure D-3e. Example of high tide flow current profile measure don October 16, 2008 at 07:50.

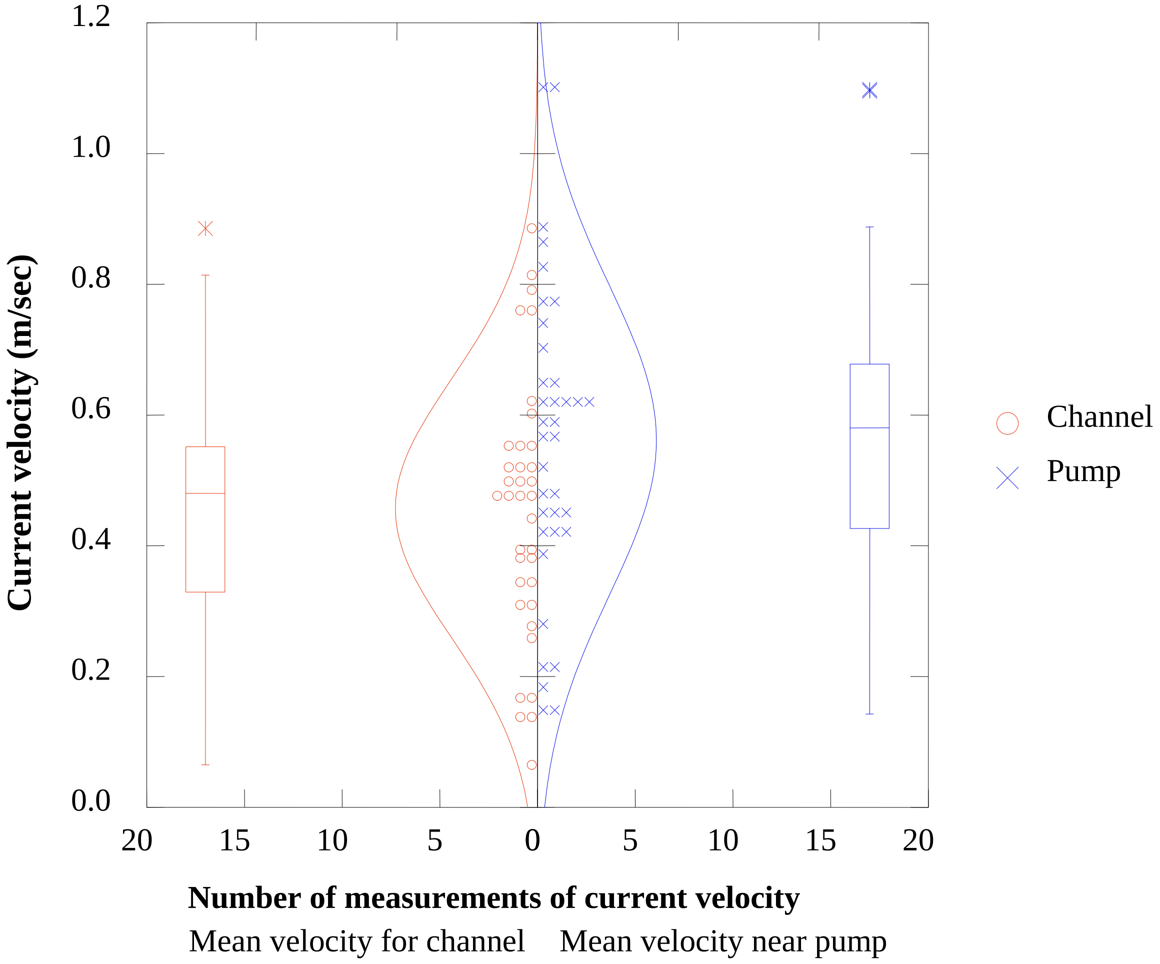

Figure D-4. Comparison of current velocity near pump intake to mean velocity in the channel overall.

The difference between current velocity near the pump and the corresponding current velocity in the overall channel was significant (p<0.05), with the former being an average of 27% greater than the latter.

Salinity profiles

Vertical profiles of water column salinity were measured from a mid-channel location when mean daily flow was <1,000 cfs. This was done to assess the presence and extent of saline water intrusion. Real-time results could be used to adjust the pump position so as to avoid collecting suspended sediments originating downstream.

Salinity profiles are plotted in the figures that follow. They show that 0.6 times the mid-channel maximum depth was always above any distinct saline layer that was present.

During the August sampling, there were 2 occasions during late flood tides and early ebb tides when salinity at the sampling depth was elevated above 3 ppT (a common threshold for freshwater). This indicated intrusion of saline water from downstream. However, the August centrifuge and sieve samples could not have contained appreciable suspended sediment from the LDW because:

- Pumping time during the 2 occasions was a small fraction of the 47-hour sampling event.
- Salinity of the water pumped during the 2 occasions was also much reduced compared to water in the upstream reaches of the LDW (expected to be 15-20 ppT).

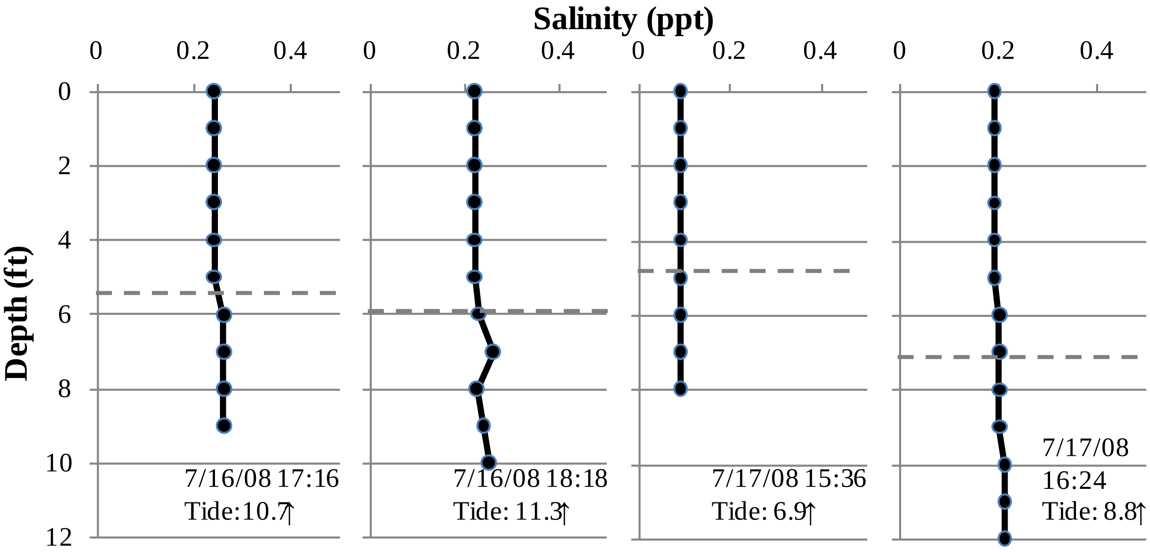

Figure D-5a. Salinity profiles for the Green River at Tukwila measured in July 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

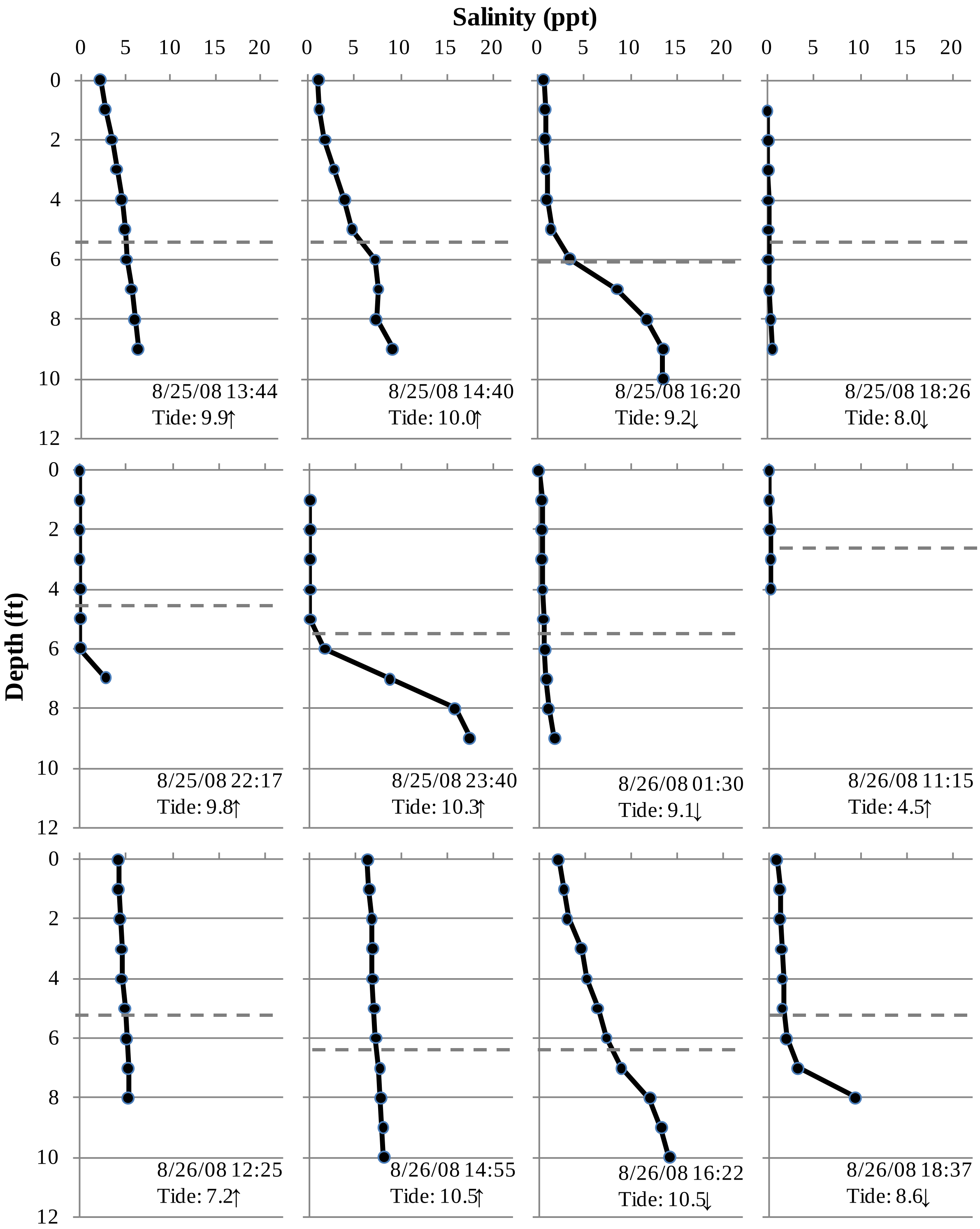

Figure D-5b. Salinity profiles for the Green River at Tukwila measured in August 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

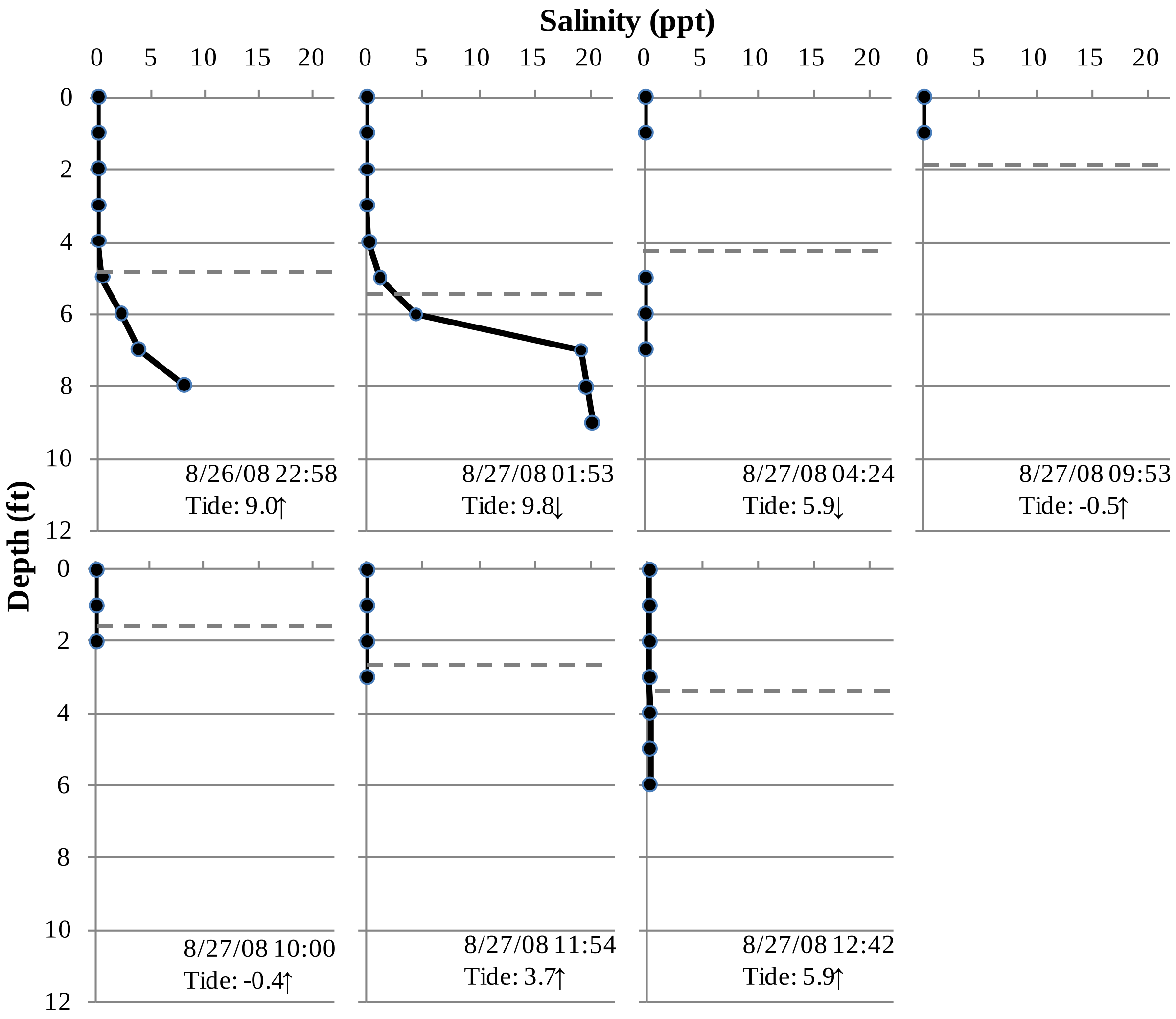

Figure D-5b (continued). Salinity profiles for the Green River at Tukwila measured in August 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

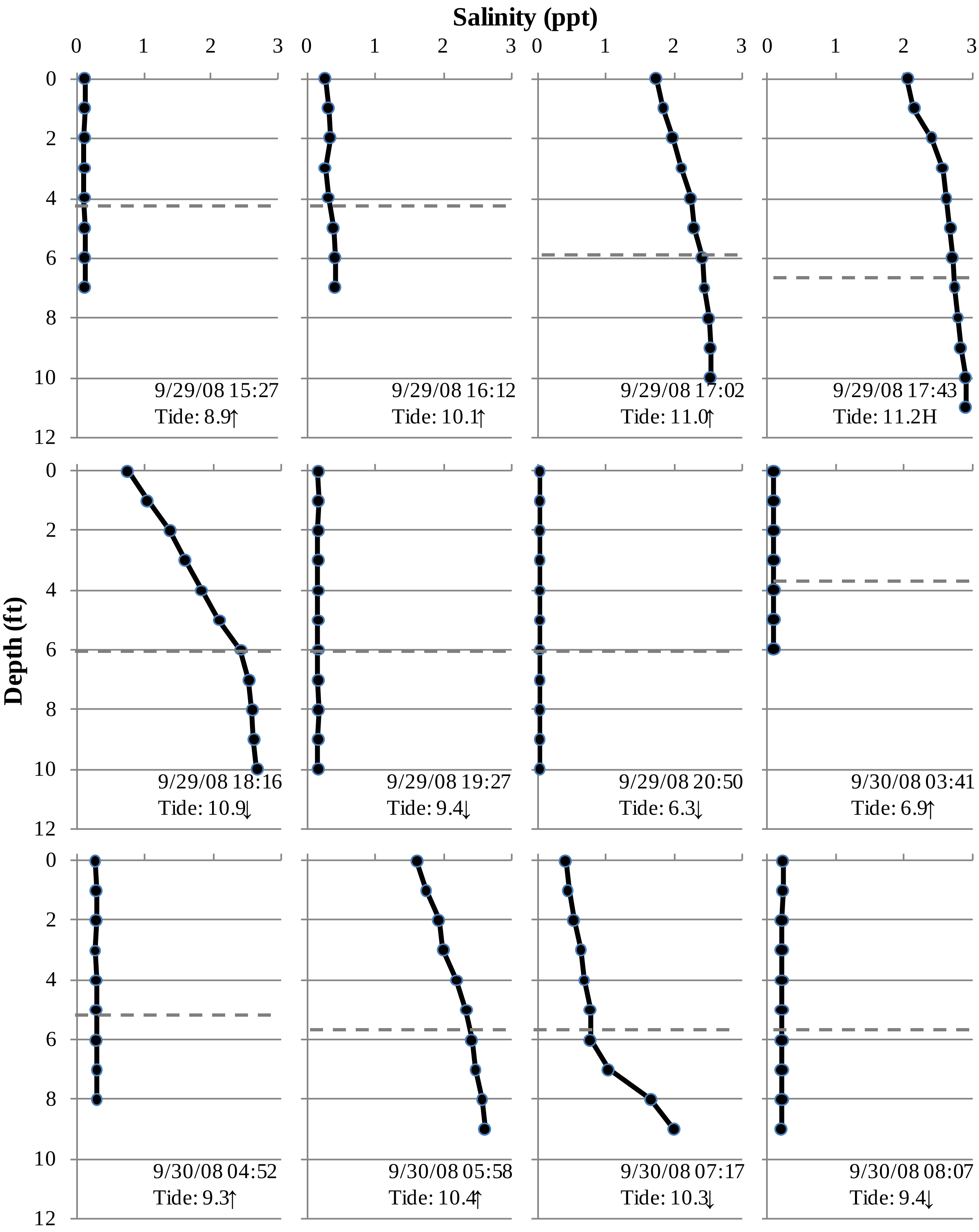

Figure D-5c. Salinity profiles for the Green River at Tukwila measured in September 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

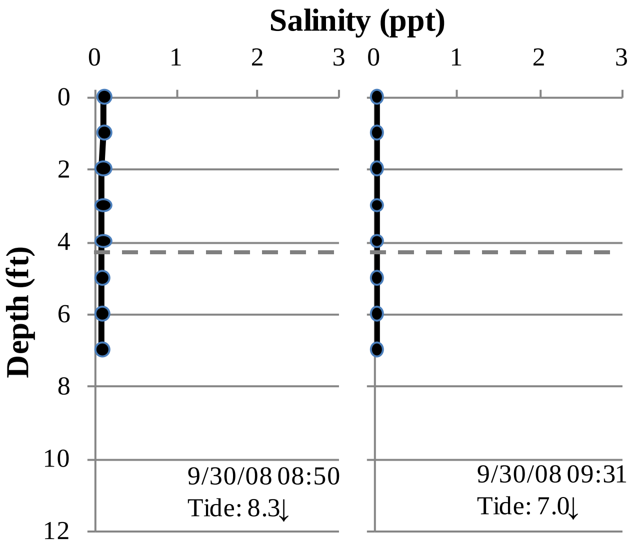

Figure D-5c (continued). Salinity profiles for the Green River at Tukwila measured in September 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

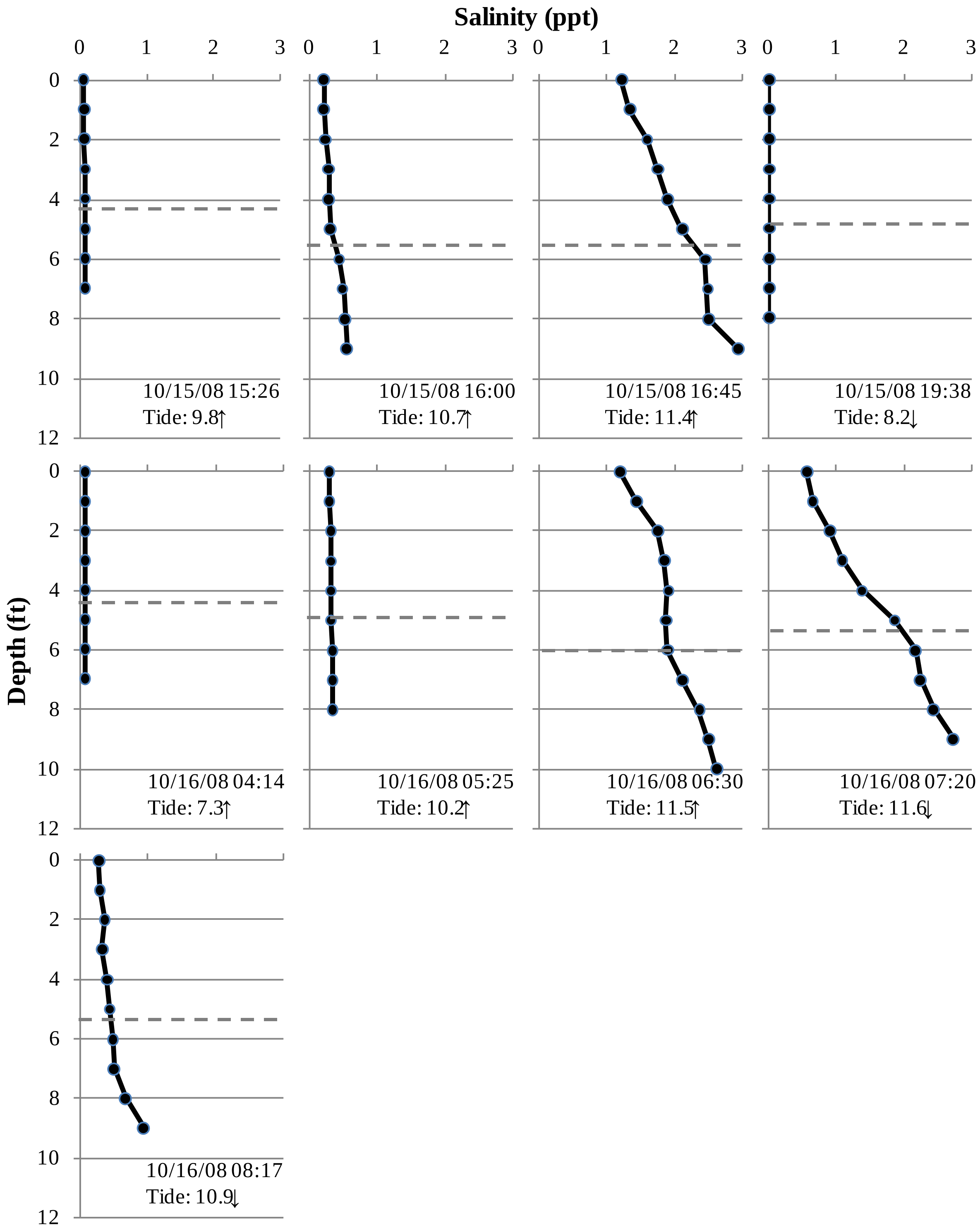

Figure D-5d. Salinity profiles for the Green River at Tukwila measured in October 2008.

Dashed lines show approximate pump position (0.6 times the maximum mid-channel depth). Arrows indicate tidal phase: upward arrow = flood tide; downward arrow = ebb tide.

Pump position

Target water depth for collecting samples of suspended sediment was 0.6 times the mid-channel maximum water depth. Current velocity at this depth is often near the mean of current velocities at all depths in the channel ("six-tenths method" of Rantz, 1982). The following figures show little difficulty in adjusting pump depth to approximately 0.6 times the maximum depth (blue). Pump depths sometimes differed from the desired depth immediately before depth was adjusted (red), especially when water levels were changing rapidly (strong ebb or flood tides).

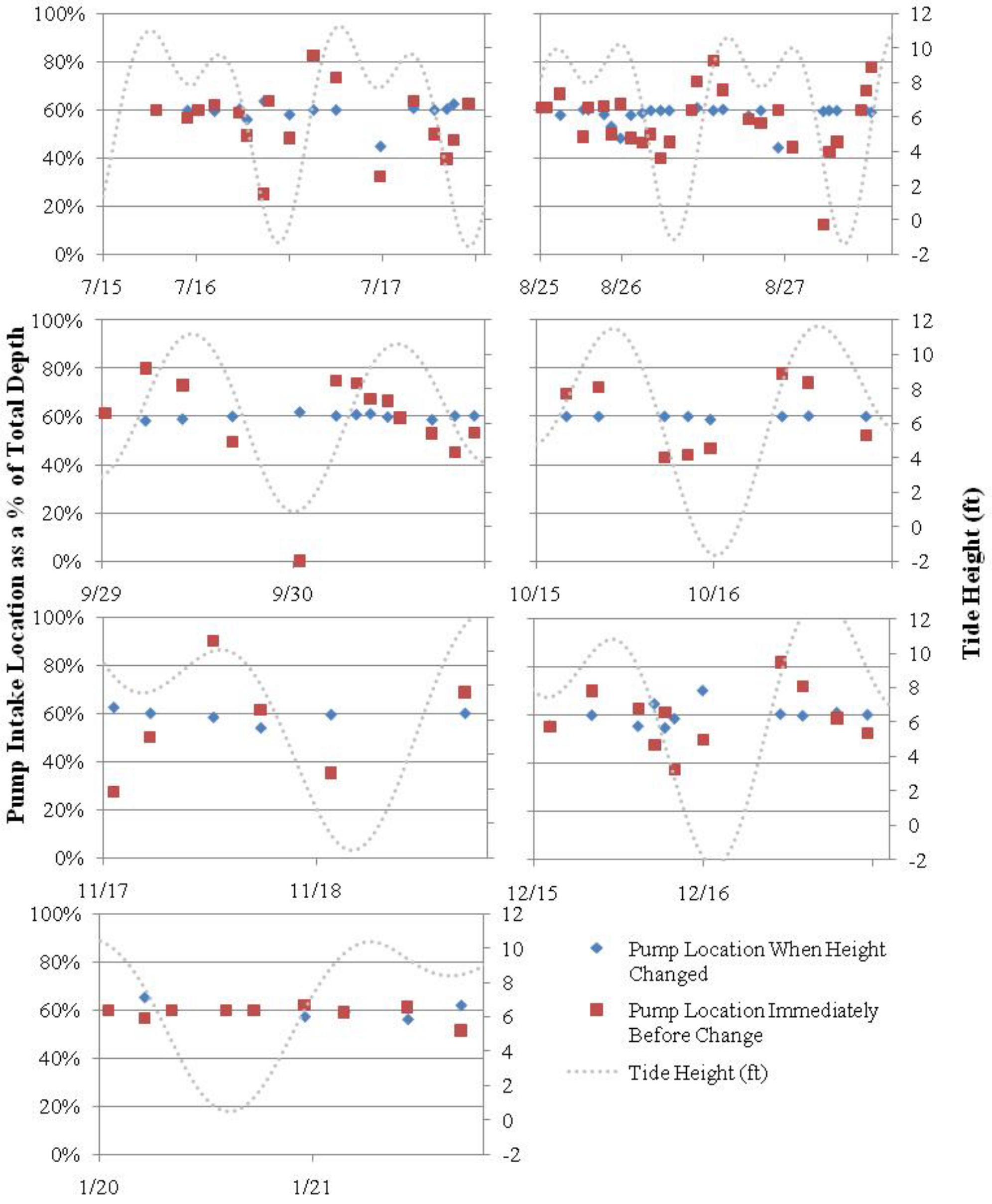

Figure D-6. Pump intake position relative to maximum mid-channel depth.

Tide heights shown were predicted for the Lower Duwamish Waterway at 8th Avenue South (www.co-ops.nos.noaa.gov/tide_pred.html).

In-situ suspended sediments

Mean particle size (diameter) and particle concentration (µl/l) was periodically measured using the LISST-Streamside instrument. Most often the instrument's pump was positioned at the same depth as the centrifuge and sieve pump and the instrument was set to collect a series of samples at 5-60 minute intervals. The LISST was also used to analyze suspended sediments present in:

- A series of vertical profiles in the river (one occasion only).
- Discrete samples of river water collected using the centrifuge pump.
- Resuspensions of sieved samples.

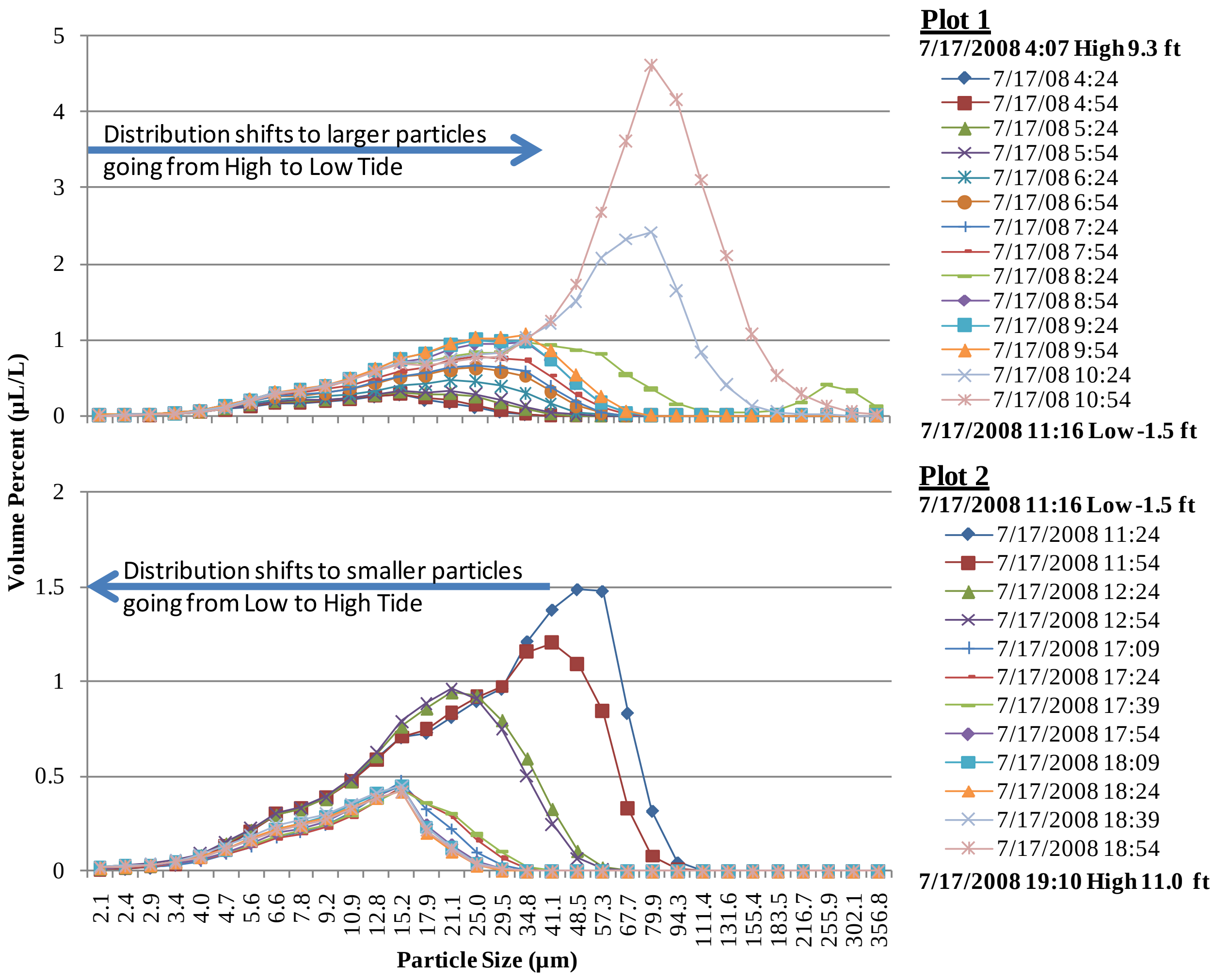

Figure D-7. Example of time-series measurements of in-situ suspended sediment.

The mean particle size (diameter) and concentration of suspended particles was observed to increase as the current velocity increased with the ebbing tide (Plot 1). The opposite pattern was observed when current velocity decreased during the flood tide (Plot 2).

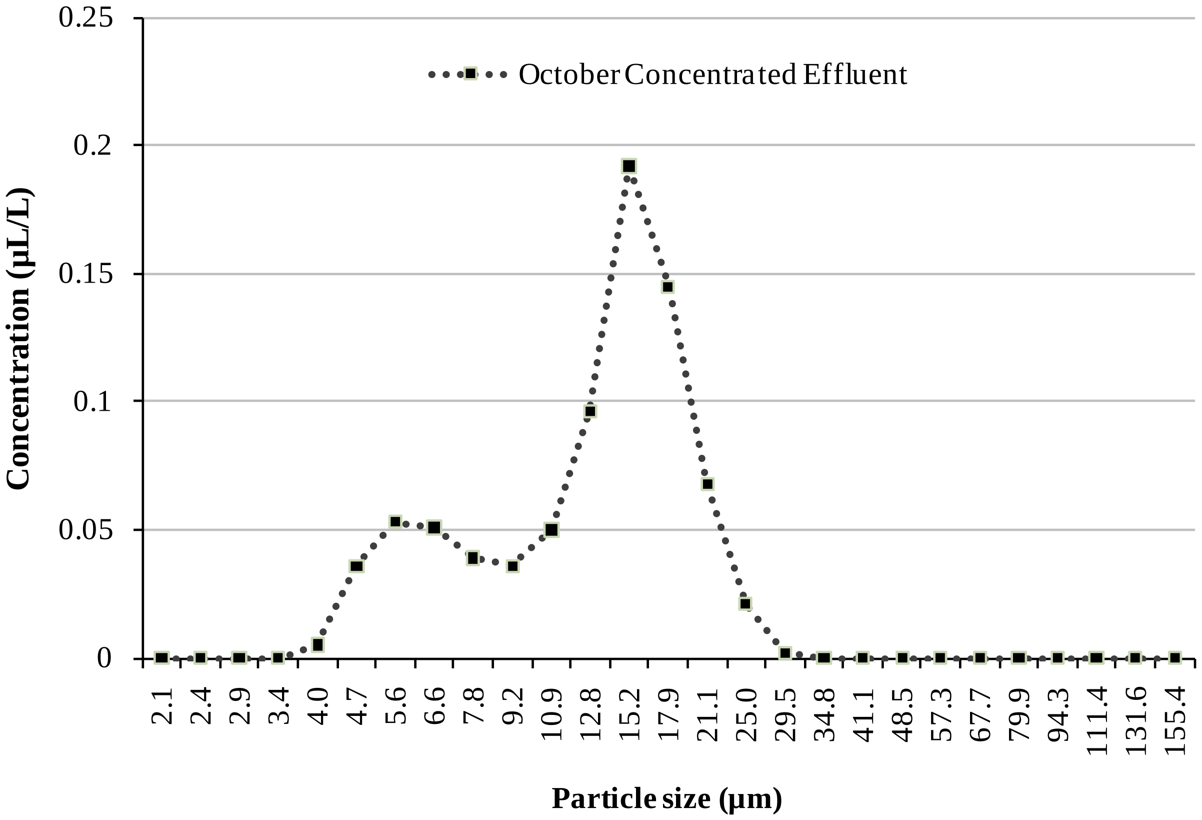

Figure D-8. Particle size distribution for material not retained by centrifuges.

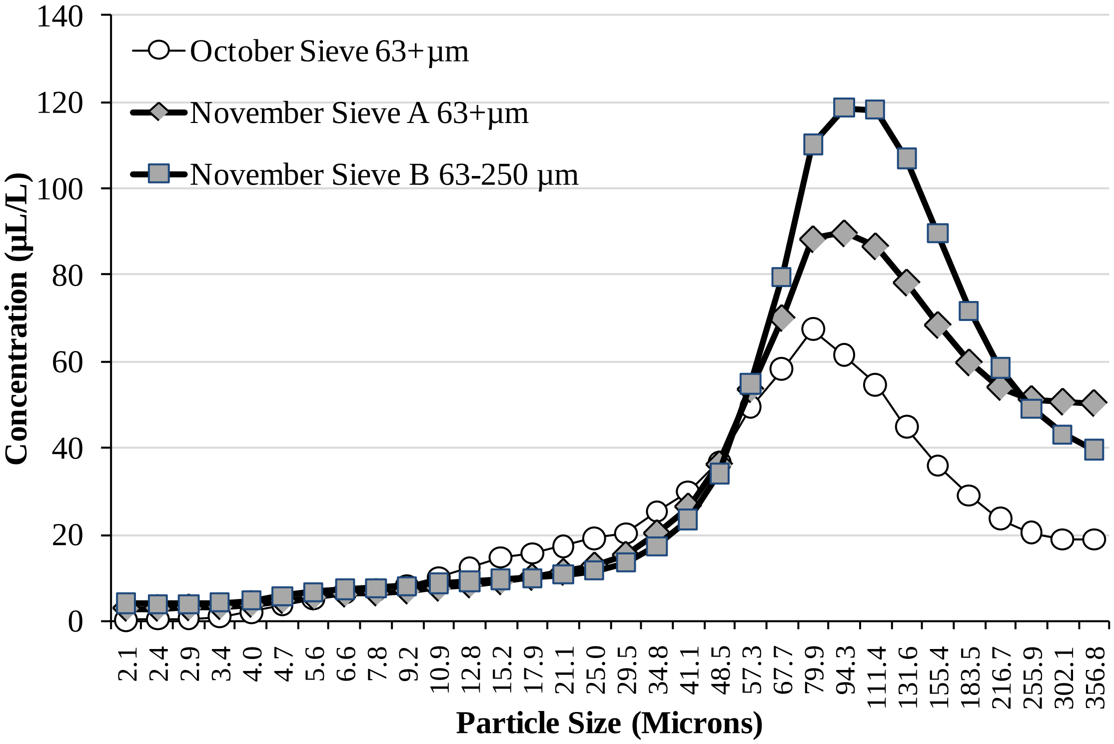

Figure D-9. Particle size distributions for subsamples of sieved sediments resuspended in water.

Appendix E. Chemistry Results

Table E-1. Summary of sampling events for contaminant loading study.

Sampling event	Start date	End date	Mean daily flow		Notes
			(cfs)	(cms)	
1	7/15/2008	7/17/2008	769	21.8	
2	8/25/2008	8/27/2008	391	11.1	Mostly sunny with intense rain on the afternoon/evening of 8/25.
3	9/29/2008	9/30/2008	517	14.6	
4	10/15/2008	10/16/2008	630	17.8	
5	11/17/2008	11/18/2008	4,225	120	
6	12/15/2008	12/16/2008	1,300	36.8	Cold (< 32°F) for entire sampling. Ice forming on river pre-dawn 12/16.
7	1/20/2009	1/21/2009	4,800	136	
Other	11/8/2008	11/8/2008	10,000	283	Subsurface grab samples only.

cfs = cubic feet per second.
cms = cubic meters per second.

Table E-2. Summary of water, sediment, and field blank samples collected.

Event ID	Sampling Date	Field ID	MEL #	Sample Type	TSS	TOC	DOC	Solids	Total PCBs	Dioxins/ Furans	PAH's	Arsenic
1	7/17/2008	River	294040	W	X	X	X					
1	7/17/2008	Effluent	294041	W	X	X	X					
1	7/17/2008	Influent	294042	W	X	X	X					
1	7/17/2008	Centrifuge	354143	S		X		X	X		X	X
1	7/17/2008	Centrifuge Disks	354143	S				X				
1	7/17/2008	Sieve A >63 µm	354145	S		X		X	X			
2	8/27/2008	Centrifuge	354130	S		X		X	X	X	X	X
2	8/27/2008	River	354131	W	X	X	X					
2	8/27/2008	Influent	354132	W	X	X	X					
2	8/27/2008	Effluent	354133	W	X	X	X					
2	8/27/2008	Sieve A >63 µm	354134+ 354135= 354146	S		X		X	X			
2	8/27/2008	Sieve A >63 µm	354135	S								
2	8/27/2008	Centrifuge Dup.	354136	S		X		X	X	X	X	
2	8/27/2008	Centrifuge Disks	354137	S		X		X	X			
3	9/30/2008	River	404060	W	X	X	X					
3	9/30/2008	Influent	404061	W	X	X	X					
3	9/30/2008	Effluent	404062	W	X	X	X					
3	9/29/2008	Field Blank	404063	W	X	X	X		X			
3	9/29/2008	Field Blank Dup.	404064	W	X	X	X					
3	9/29/2008	Discrete 1	404065	W	X	X	X					
3	9/29/2008	Discrete 2	404066	W	X	X	X					
3	9/29/2008	Discrete 3	404067	W	X	X	X					
3	9/29/2008	Discrete 4	404068	W	X	X	X					
3	9/30/2008	Discrete 5	404069	W	X	X	X					
3	9/30/2008	Discrete 6	404070	W	X	X	X					
3	9/30/2008	Discrete 7	404071	W	X	X	X					
3	9/30/2008	Discrete 8	404072	W	X	X	X					
3	9/30/2008	Centrifuge	404073	S		X		X	X	X	X	X
3	9/30/2008	Sieve A >63 µm	404074	S				X	X			
3	9/30/2008	Centrifuge Water	404078	W	X							
4	10/16/2008	River	414180	W	X	X	X					
4	10/16/2008	Influent	414181	W	X	X	X					
4	10/16/2008	Effluent	414182	W	X	X	X					
4	10/16/2008	Centrifuge	414183	S		X		X	X	X	X	X
4	10/16/2008	Sieve A >63 µm	414184	S		X		X	X			
4	10/16/2008	Sieve B >63 µm	414185	S				X			X	X
-	11/13/2008	A	464022	W	X	X	X					
-	11/13/2008	B	464023	W	X	X	X					
-	11/13/2008	C	464024	W	X	X	X					
5	11/17/2008	Field Blank	474291	W		X			X	X	X	X
5	11/17/2008	Field Blank Dup.	474291	W						X		
5	11/18/2008	Centrifuge	474280	S		X		X	X	X	X	X
5	11/18/2008	Centrifuge Dup.	474280	S				X	X	X		
5	11/18/2008	Sieve B 63-250 µm	474281	S		X		X	X	X	X	X
5	11/18/2008	Sieve A >63 µm	474282	S		X		X	X	X	X	X
5	11/18/2008	Sieve B >250 µm	474283	S		X		X	X		X	X

Event ID	Sampling Date	Field ID	MEL #	Sample Type	TSS	TOC	DOC	Solids	Total PCBs	Dioxins/ Furans	PAH's	Arsenic
5	11/18/2008	River	474284	W	X	X	X					
5	11/18/2008	Influent	474285	W	X	X	X					
5	11/18/2008	Effluent	474286	W	X	X	X					
5	11/18/2008	Blank	474287	W	X	X	X					
5	11/18/2008	Blank Dup.	474289	W	X	X	X					
6	12/16/2008	Centrifuge	514030	S		X		X	X	X	X	X
6	12/16/2008	Sieve A >63 µm	514031	S		X		X	X			
6	12/16/2008	Sieve B 63-250 µm + >250 µm	514032 + 514033	S				X			X	X
6	12/16/2008	River	514034	W	X	X	X					
6	12/16/2008	Influent	514035	W	X	X	X					
6	12/16/2008	Effluent	514036	W	X	X	X					
7	1/21/2009	River	90102201	W	X	X	X					
7	1/21/2009	Influent	90102202	W	X	X	X					
7	1/21/2009	Effluent	90102203	W	X	X	X					
7	1/21/2009	Blank	90102204	W	X	X	X					
7	1/21/2009	Blank Dup.	90102205	W	X	X	X					
7	1/21/2009	Field Blank	90102206	W					X	X	X	X
7	1/20/2009	Discrete 1	90102207	W	X	X	X					
7	1/20/2009	Discrete 2	90102208	W	X	X	X					
7	1/20/2009	Discrete 3	90102209	W	X	X	X					
7	1/20/2009	Discrete 4	90102210	W	X	X	X					
7	1/21/2009	Discrete 5	90102211	W	X	X	X					
7	1/21/2009	Discrete 6	90102212	W	X	X	X					
7	1/21/2009	Discrete 7	90102213	W	X	X	X					
7	1/21/2009	Discrete 8	90102214	W	X	X	X					
7	1/21/2009	Centrifuge	90102216	S		X		X	X	X	X	X
7	1/21/2009	Sieve A >63 µm	90102217	S		X		X	X	X	X	X
7	1/21/2009	Sieve B 63-250 µm	90102218	S		X		X	X	X	X	X
7	1/21/2009	Sieve B Dup. 63-250 µm	90102218	S					X			
7	1/21/2009	Sieve B >250 µm	90102219	S		X		X	X	X	X	X
7	1/22/2009	Sieve B >250 µm Dup.	90102220	S				X		X		
Total number of samples					47	66	46	25	25	17	18	17

MEL = Manchester Environmental Laboratory.
TSS = total suspended solids.
TOC = total organic carbon.
DOC = dissolved organic carbon.
Solids = % solids (usually air-dried).
PCBs = polychlorinated biphenyls.
PAHs = polycyclic aromatic hydrocarbons.
Dup. = sample duplicate.
S = sediment (centrifuged or sieved from the water column).
W = water.

Table E-3. Results for conventional parameters in water samples.

Month (2008-2009)	Total Suspended Solids (TSS, mg/L)				Total organic carbon (TOC, mg/L)				Dissolved organic carbon (DOC, mg/L)				Calculated Parameters								
	River composites	River - discrete samples (mean)	Centrifuge influent	Centrifuge effluent	River composites	River – discrete samples (mean)	Centrifuge influent	Centrifuge effluent	River composites	River – discrete samples (mean)	Centrifuge influent	Centrifuge effluent	POC River = TOC-DOC (mg/L)	POC Centrifuge influent = TOC-DOC (mg/L)	Composite /Discrete TSS (%)	Centrifuge influent /River TSS (%)	Centrifuge influent /River TOC (%)	Centrifuge influent /River DOC (%)	Centrifuge efficiency (%) [1-(Effluent/Influent)]*100	Centrifuge influent POC/TSS (%)	Centrifuge influent DOC/TOC (%)
Jul	5	-	5	0.4U	1.4	-	1.3	1.3	1.2	-	1.2	1.3	0.2	0.1	-	1.2	92.9	100	92	2	92.3
Aug	8	-	10	0.5	2.2	-	2.2	2	2.1	-	1.9	1.9	0.1	0.3	-	1.2	100	90.5	95	3	86.4
Sep	6.3	5.7	7.1	0.3U	1.4	1.35	1.35	1.2	1.2	1.2	1.2	1.2	0.2	0.2	110	113	96.4	100	95.3	3	88.9
Oct	5.6	-	6.7	0.3U	1.3	-	1.3	1.3	1.2	-	1.2	1.1	0.1	0.1	-	120	100	100	95.5	1.5	92.3
Nov	47	-	56.5	0.4	2.5	-	2.4	2.1	1.9	-	1.85	1.8	0.6	0.6	-	120	96	97.4	99.3	1	77.1
Dec	6.9	-	6.4	0.3	2.15		2	2	1.9	-	1.9	1.9	0.3	0.1	-	92.8	93	100	95.3	1.5	95
Jan	66	68.9	76	1.0U	1.6	1.2	1.1	1.15	1.1	1.1	1.0	1	0.5	0.1	95.8	115	68.8	90.9	98.7	0.1	90.9
Nov 8	-	209	-	-	-	4.8	-	-	-	4.1	-	-	0.7	-	-	-	-	-	-	-	-

Table E-4. Results for conventional parameters in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	Volume pumped (gal)	Volume pumped (L)	Wet sediment MEL (g)	Dry sediment MEL (g)	Air-dried solids MEL (%)	Wet sediment collected (g)	Dry sediment collected (g)	Dry mass/vol. pumped (mg/L)	Influent TSS (mg/L)	Centrifuge Efficiency (second estimate)	Fraction <63µm	Fraction >63µm	TOC (%)
July	Centrifuge	-	-	291.4	67.94	23.31	334	78	4.12	-	-	-	-	5.0 J
	Centrifuge Disks	-	-	27.26	8.42	30.91	52.5	16	0.86	-	-	-	-	-
	Centrifuge Total	4989	18885	-	-	-	386.5	94.1	4.98	5.0	99.6	0.928	0.072	-
	Sieve A >63	4104	15535	31.59	5.62	17.79	31.6	5.62	0.36	-	-	-	-	9.62 J
August	Centrifuge	-	-	67.63	20.6	30.46	682	186.7	-	-	-	-	-	6.01 J
	Centrifuge Dup.	-	-	82.19	20.41	24.83			-	-	-	-	-	-
	Centrifuge Disks	-	-	63.44	5.33	8.4	66	5.5	-	-	-	-	-	-
	Total Centrifuge	5142	19465	-	-	-	748	192.2	9.88	10.0	98.8	0.936	0.064	-
	Sieve A >63	3101	11739	52.94	7.35	13.89	52.9	7.35	0.63	-	-	-	-	7.53 J
September	Centrifuge	2713	10270	48.87	11.55	23.63	263	62.16	6.05	7.1	85.2	0.878	0.122	5.4 J
	Sieve A >63	2319	8778	39.02	6.19	15.86	41	6.5	0.74	-	-	-	-	-
October	Centrifuge	2640	9993	54.48	13.14	24.13	234	56.45	5.65	6.7	84.3	0.821-0.872	0.128-0.179	5.26 J
	Sieve A >63	3351	12685	54.12	8.47	15.64	58.7	9.18	0.72	-	-	-	-	-
	Sieve B >63	7035	26630	112.3	24.89	22.16	121.7	26.97	1.01	-	-	-	-	-

Month (2008-2009)	Sample type (suspended sediment)	Volume pumped (gal)	Volume pumped (L)	Wet sediment MEL (g)	Dry sediment MEL (g)	Air-dried solids MEL (%)	Wet sediment collected (g)	Dry sediment collected (g)	Dry mass/vol. pumped (mg/L)	Influent TSS	Centrifuge Efficiency (second estimate)	Fraction <63µm	Fraction >63µm	TOC (%)
November	Centrifuge	2518	9532	64.06	32.46	50.7	1048	531	55.7	56.5	98.6	0.763-0.819	0.181-0.237	2.15 J
	Centrifuge Dup.	2518	9532	63.9	32.35	50.6	1048	530.6	55.7	56.5	98.6	-	-	-
	Sieve A >63	3489	13207	161	87.26	54.2	247	133.8	10.1	-	-	-	-	2.42 J
	Sieve B 63-250	3791	14350	163.6	93.81	57.3	246	141.1	9.8	-	-	-	-	1.88 J
	Sieve B >250	3791	14350	98.15	40.84	41.6	116	48.3	3.4	-	-	-	-	2.85 J
December	Centrifuge	2415	9142	58.28	18.53	31.79	209	66.4	7.3	6.4	114	0.712-0.795	0.205-0.288	4.56 J
	Sieve A >63	4080	15444	68.04	21.7	31.89	73	23.3	1.5	-	-	-	-	4.02 J
	Sieve B 63-250 combined with Sieve B >250	5950	22523	94.03	38.37	40.8	116	47.3	2.1	-	-	-	-	-
January	Centrifuge	2193	8301	90.88	49.24	54.18	1332	721.7	86.9	76	113	-	-	1.72 J
	Sieve A >63	2501	9467	197.07	115.34	58.53	292	170.9	18.1	-	-	0.739-0.792	0.208-0.261	1.84 J
	Sieve B 63-250	3214	12166	215.11	132.84	61.75	313	193.3	15.9	-	-	-	-	1.63 J
	Sieve B >250	3214	12166	113.85	59.56	52.31	157	82.1	6.8	-	-	-	-	2.39 J

Table E-5. Results for Total PCBs in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	PCB - 1016	PCB - 1221	PCB - 1232	PCB - 1242	PCB - 1248	PCB - 1254	PCB - 1260	PCB - 1262	PCB - 1268	Sum using detects Only
July	Centrifuge	2.5 U	2.5 U	2.5 U	2.5 U	3.2 J	4.3 J	2.5 U	2.5 U	2.5 U	7.5 J
	Sieve A >63	5.5 U	5.5 U	5.5 U	2.9 J	5.5 U	5.2 J	5 J	5.5 U	5.5 U	13.1 J
August	Centrifuge	9.9 UJ	5 UJ	5 UJ	9.9 UJ	15 J	27 J	14 J	15 UJ	5 UJ	56 J **
	Centrifuge Dup.	10 UJ	2.5 U	5 UJ	10 UJ	23 J	33 J	15 J	15 UJ	2.5 U	71 J
	Disk Sediment	5.9 U	12 UJ	12 UJ	5.9 U	12 J	22 J	15 J	12 UJ	5.9 U	49 J
	Sieve A >63	8.1 UJ	4.1 U	4.1 U	16 UJ	20 J	35 J	14 J	16 UJ	8.1 UJ	69 J
September	Centrifuge	2.2 U	2.2 U	2.2 U	2.2 U	4.7 UJ	6.8 J	4	4.3 UJ	2.2 U	10.8 J
	Sieve A >63	4.1 U	4.1 U	4.1 U	4.1 U	4.1 U	6.2 J	4.1 U	4.1 U	4.1 U	6.2 J
October	Centrifuge	1.9 U	1.9 U	1.9 U	3.8 UJ	3.5 J	8.7 J	3.6	3.8 UJ	1.9 U	15.8 J
	Sieve A >63	3 U	3 U	3 U	3 U	4.5 J	7.7 J	3 U	3 U	3 U	12.2 J
November	Centrifuge	1.2 U	2.5 UJ	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	2.5 UJ
	Centrifuge	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	2.5 UJ	1.2 U	2.5 UJ
	Sieve A >63	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
	Sieve B 63-250	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
	Sieve B >250	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	3.3 J	1.2 U	1.2 U	1.2 U	3.3 J
December	Centrifuge	1.4 U	2.7 UJ	2.7 UJ	1.4 U	1.4 U	2.7 UJ	2.7 UJ	2.7 UJ	1.4 U	2.7 UJ
	Sieve A >63	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	2.3 J	1.9 UJ	1.2 U	1.2 U	2.3 J
January	Centrifuge	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
	Sieve A >63	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
	Sieve B 63-250	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
	Sieve B >250	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U	1.2 U
Quality Control											
September	Field Blank	0.0031 U	0.0031 U	0.0031 U	0.0031 U	0.0076 UJ	0.0031 U	0.0031 U	0.0031 U	0.0031 U	0.0076 U
November	Field Blank	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U	0.0033 U

** = The value used to represent suspended sediment (62.1 µg/kg) is the mean of centrifuge duplicates *adjusted by the result for the disk sediment.*

Table E-6. Results for chlorinated dibenzo-p-dioxins and dibenzo furans (PCDD/Fs) in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	Dioxins or PCDDs (ng/Kg)						
		2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD
August	Centrifuge	1.64	3.32	20.4	24	11.3	399	2750
	Centrifuge Dup.	2.46	2.77	4.56	12.8	8.87	297	2070
September	Centrifuge	1.14	2.34	2.1	6.16	6.09	172	1650
October	Centrifuge	1.68	0.5 UJ	1.43	4.28	3.01	102	700
November	Centrifuge	0.77	0.5 U	0.5 U	0.5 U	0.55	12.6	92.8
	Centrifuge Dup.	0.64	0.5 U	0.5 U	0.5 U	0.53	12.8	96.9
	Sieve A >63	0.2 U	0.5 U	1.36	0.92	0.5 U	25.1	183
	Sieve B 63-250	0.2	0.5	0.5	0.5	0.5	11.2	97.8
December	Centrifuge	0.2	0.5	0.5	0.5	1.38	39.7	310
	Centrifuge	0.2 U	0.5 UJ	0.5 UJ	0.5 UJ	1.38	39.7	310
January	Centrifuge	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	12	79.3
	Sieve A >63	0.2 U	0.5 U	0.5 U	0.5 U	0.88	46.5	412
	Sieve B 63-250	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	4.47	24.3
	Sieve B >250	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	15.5	122
	Sieve B >250 Dup.	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	11.5	106
Quality Control								
November	Field Blank	1 U	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	4 UJ
	Field Blank Dup.	1 U	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	4 UJ
January	Field Blank	1 U	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	4 UJ

Table E-6 continued. Results for chlorinated dibenzo-p-dioxins and dibenzo furans (PCDD/Fs) in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	Furans or PCDFs (ng/Kg)										Total PCDD/Fs TEQ (Van den Berg et al., 2006)			
		2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Lower (ND=0)	Mid (ND=1/2DL)	Upper (ND=DL)	Solids (for D/F samples)
August	Centrifuge	0.72 U	1.45	1.66	5.25	3.82	5.4	2.43	73.4	6.79	197	18.5	18.5	18.5	30.2
	Centrifuge Dup.	0.2 U	1.14	1.54	4.92	3.27	3.97	1.82	49.1	3.64	139	13.9	13.9	13.9	30.5
September	Centrifuge	0.2 U	0.5 UJ	0.71J	2.01	1.86	2.06 UJ	0.5	30.7	2.63	95.4	8.33	8.36	8.39	32.2
October	Centrifuge	1.92	0.71 J	0.52 J	1.09	0.86	1.41	0.5 UJ	19.1	0.7 UJ	52	4.69	4.97	5.25	31.4
November	Centrifuge	0.25	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	1.37	0.7 U	7.37	1.02	1.51	1.99	56.1
	Centrifuge Dup.	0.35	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.21	0.7 U	7.11	0.909	1.4	1.88	56.1
	Sieve A >63	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.7 U	0.7 U	9.11	0.537	1.11	1.69	55.4
	Sieve B 63-250	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.7 U	0.7 U	1 U	0.141	0.766	1.39	60.4
December	Centrifuge	0.2 U	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	14.9	0.7 U	22.3	0.784	1.38	1.98	44.9
January	Centrifuge	0.43	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.44	0.7 U	24.4	0.219	0.83	1.44	51.3
	Sieve A >63	0.29	0.5 U	0.5 U	1.62	0.5 U	0.5 U	0.5 U	6.18	1.84	34.1	0.958	1.52	2.07	58.8
	Sieve B 63-250	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.7 U	0.7 U	1.01	0.052	0.677	1.3	56.9
	Sieve B >250	0.2 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.61	0.7 U	6.95	0.22	0.841	1.46	64.9
	Sieve B >250 Dup.	0.36 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.06	0.7 U	6.61	0.205	0.816	1.43	64.9
Quality Control															
November	Field Blank	1 UJ	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	3 UJ	4 UJ				
	Field Blank Dup.	1 UJ	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	3 UJ	4 UJ				
January	Field Blank	1 U	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	3 UJ	3 UJ	4 UJ				

Table E-7. Results for low molecular weight PAH (LPAH) in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	2-Methylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Fluorene	Naphthalene	Phenanthrene	Total LPAH
July	Centrifuge	2.7 J	25 UJ	2.5 J	25 U	25 UJ	25 UJ	30	35.2 J
August	Centrifuge	4.6 J	2.9 J	17 J	33	26 UJ	6 NJ	186	243.5 J
	Centrifuge Dup.	24 J	12 J	22 J	48	31 UJ	23 J	316	445 J
September	Centrifuge	22 U	22 U	22 U	8.3 J	22 U	16 J	74	98.3 J
October	Centrifuge	11 J	21 U	21 U	62	21 U	27	196	296
	Sieve B >63	17 U	17 U	2.1 J	8.6 J	17 U	5.6 J	51	67.3 J
November	Centrifuge	12 U	12 U	12 U	2.7 J	12 U	5.9 J	26	34.6 J
	Sieve B 63-250	12 U	12 U	12 U	3.8 J	12 U	3.4 J	42	49.2 J
	Sieve B >250	12 U	12 U	12 U	3.4 J	12 U	8.9 J	35	47.3 J
	Sieve B >250	12 UJ	12 UJ	12 UJ	5.1 J	12 UJ	5.1 J	47	57.2 J
December	Centrifuge	15 U	15 U	1.7 J	7.1 J	15 U	4.8 J	46	59.6 J
	Sieve B >63	12 U	12 U	2.3 J	8.2 J	12 U	6.8 J	52	69.3 J
January	Centrifuge	12 U	12 U	12 U	3.6 J	12 U	8.2 J	30	41.8 J
	Sieve A >63	12 U	12 U	12 U	5.8 J	12 U	10 J	44	59.8 J
	Sieve B 63-250	12 U	12 U	12 U	3.4 J	12 U	7.2 J	32	42.6 J
	Sieve B >250	12 U	12 U	12 U	3.8 J	12 U	13	42	58.8
Quality Control									
November	Field Blank	0.01 U	0.01 UJ	0.01 U	0.01 U	0.01 UJ	0.03 UJ	0.01 U	
January	CONTAMBLK (Field blank)	0.034 UJ	0.028 U	0.028 U	0.028 U	0.028 U	0.039 UJ	0.028 U	

Table E-8. Results for high molecular weight PAH (HPAH), including carcinogenic PAH (cPAH), in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(ghi)perylene	Benzo(k)fluoranthene	Chrysene	Dibenzo(a,h)anthracene	Fluoranthene	Indeno(1,2,3-cd)pyrene	Pyrene	Total HPAH	cPAH
July	Centrifuge	26	29	60	50	19 J	44	22 J	59	97 J	49	455 J	52J
August	Centrifuge	246	372	813	579	287	601	106	638	516	505	4660	580
	Centrifuge Dup.	254	390	870	588	278	628	107	732	552 J	750	5150 J	600
September	Centrifuge	25	23	24	17 J	12 J	35	22 U	64	70	60	330	38
October	Centrifuge	166	108	117	50	59	195	21 U	365	101	382	1540	155
	Sieve B 63-250	31	34	63	50	25	62	17 U	90	80	84	520	55
November	Centrifuge	8.1 J	6.8 J	6.1 J	7.1 J	5.1 J	14	12 U	17	36	18	118 J	13.1J
	Sieve A >63	17	13	16	9.5 J	8.3 J	23	12 U	39	40	39	205	22
	Sieve B 63-250	14	11 J	12 J	7.5 J	5.5 J	19	12 U	35	37	34	175 J	19J
	Sieve B >250	13	11 J	10 J	8.4 J	6.2 J	17	12 U	28	38	27	159 J	18.5J
December	Centrifuge	25	26	50	36	23	51	26	75	66	70	448	46
	Sieve B >63	33	44	77	58	36	71	12 U	105	72	94	590	67
January	Centrifuge	10 J	8.7 J	11 J	8.1 J	5 J	15	12 U	22	37	23	140 J	16
	Sieve A >63	14	12 J	9.4 J	7.1 J	7.1 J	19	4.2 J	28	38	30	169 J	20
	Sieve B 63-250	10 J	7.7 J	6.5 J	5.8 J	5.1 J	15	12 U	24	37	24	135 J	14
	Sieve B >250	7.1 J	4 J	1.8 J	2.3 J	3.6 J	11 J	6.2 J	17	33	17	103 J	9.3
Quality Control													
November	FIELDBLK	0.01 U	0.01 U	0.01 U	0.01 UJ	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 UJ	
January	CONTAMBLK	0.028 U	0.028 U	0.028 U	0.028 U	0.028 U	0.028 U	0.028 UJ	0.028 U	0.028 U	0.028 U	0.028 UJ	

Table E-9. Results for arsenic in centrifuged and sieved sediment samples.

Month (2008-2009)	Sample type (suspended sediment)	Arsenic
July	Centrifuge	13.5
August	Centrifuge	22.3
	Centrifuge Dup.	22.5
September	Centrifuge	24.3
October	Centrifuge	23.6
	Sieve A >63	11.1
November	Centrifuge	9.2
	Sieve B 63-250	4.83
	Sieve B >250	5.08
December	Centrifuge	14
	Sieve A >63	5.28
	Sieve B 63-250	4.84
January	Centrifuge	9.39
	Sieve A >63	3.57
	Sieve B 63-250	4.78
	Sieve B >250	5.34
Quality Control		
November	Field Blank	0.1 U
January	CONTAMBLK	0.1 U

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Appendix F. Loading Calculations

Table F-1. Example calculation of daily and annual sediment load.

Daily load of suspended sediment (kg/day) was predicted using the mean daily flows and a rating curve for the Green River at Auburn, Washington (http://waterdata.usgs.gov/usa/nwis/uv?site_no=12113000); Embrey and Frans, 2003).

Summing daily loads resulted in estimates of annual sediment load. Note: 1975 was a year with high flows and sediment loads.

Mean daily flow (Q)				Daily sediment load was predicted using the rating equation: ln(daily sediment load)(lb/day) = $\ln(L_{sus})$ = $12.6 + 1.8916*[\ln(Q^*)] + 0.33201[\ln(Q^*)]^2$ where $\ln(Q^*) = \ln(Q \text{ in cfs}) - \ln(1800\text{cfs})$	
Flow Station Auburn	Date	Q (cfs)	Q (l/d)	Predicted Daily Sediment Load (converted to kg/d)	SSC (mg/L) [Load (kg/d) x 10^6] ÷ Q (l/d)
12113000	1/2/1975	1500	3669883200	96539	26.3
12113000	1/3/1975	1510	3694349088	97683	26.4
12113000	1/4/1975	1480	3620951424	94277	26.0
12113000	1/1/1975	1640	4012405632	113361	28.3
12113000	1/5/1975	1780	4354928064	131986	30.3
⋮	⋮	⋮	⋮	⋮	⋮
12113000	12/27/1975	6800	16636803840	2994434	180
12113000	12/28/1975	4770	11670228576	1167472	100
12113000	12/29/1975	4390	10740524832	947784	88.2
12113000	12/30/1975	5160	12624398208	1428194	113
12113000	12/31/1975	4510	11034115488	1013683	91.9
Annual Total				**218,000 mT (rounded from 217,684)**	

Q = mean daily discharge or flow (cfs or l/d).
ln = natural logarithm.
SSC = suspended solids concentration.
(See Appendix A for definitions of units of measurement.)

Table F-2. Example calculation of daily and annual load of contaminants associated with suspended sediment.

Daily sediment load was predicted as in Table F-1. Daily contaminant concentrations were predicted from mean daily flow and regression equations derived from results of this 2008-09 study. Lower-bound contaminant loads were approximated assuming low concentrations associated with sediments suspended during all high-flow events and could be predicted using mean daily flow and the regression derived from results of this study. Upper-bound loads were approximated assuming concentrations were elevated and that August centrifuge sample concentrations could be assigned to the first two days of each high-flow event.

						Approximate Lower Bound PCB Load Levels predicted from regression: PCBs (µg/kg) = 28275 x [Q (cfs) ^ -1.184]		Daily Flow >150% of previous day?	*Approximate* Upper Bound PCB Load Same except August centrifuge sample concentration assigned for 2 days when daily flow increased by >150% (bold)	
Flow Station Auburn	Date	Daily Flow Q (cfs)*	Daily Flow Q (l/d)	Sediment Load (kg/day)	SSC (mg/L)	Total PCB (µg/kg)	PCB Load (g/d)		Total PCB (µg/kg) **	PCB Load (g/d)
12113000	1/1/1975	1500	3669883200	96539	26.3	4.9	0.47		4.9	0.47
12113000	1/2/1975	1510	3694349088	97683	26.4	4.9	0.48		4.9	0.48
12113000	1/3/1975	1480	3620951424	94277	26.0	5.0	0.47		5.0	0.47
12113000	1/4/1975	1640	4012405632	113361	28.3	4.4	0.50		4.4	0.50
12113000	1/5/1975	1780	4354928064	131986	30.3	4.0	0.53		4.0	0.53
12113000	1/6/1975	2220	5431427136	203384	37.4	3.1	0.63		3.1	0.63
12113000	1/7/1975	1970	4819779936	160325	33.3	3.6	0.57		3.6	0.57
12113000	1/8/1975	1750	4281530400	127838	29.9	4.1	0.52		4.1	0.52
12113000	1/9/1975	1640	4012405632	113361	28.3	4.4	0.50		4.4	0.50
12113000	1/10/1975	1430	3498621984	88773	25.4	5.2	0.46		5.2	0.46
12113000	1/11/1975	1350	3302894880	80406	24.3	5.6	0.45		5.6	0.45
12113000	1/12/1975	**1700**	4159200960	121116	29.1	4.2	0.51		**62**	7.5
12113000	1/13/1975	**3530**	8636458464	560263	64.9	1.8	1.00	Y	**62**	34.7
12113000	1/14/1975	**5760**	14092351488	1906809	135	1.0	1.90	Y	**62**	118
12113000	1/15/1975	4180	10226741184	839816	82.1	1.5	1.22		1.5	1.22
12113000	1/16/1975	**3060**	7486561728	403835	53.9	2.1	0.85		**62**	25.0

						Approximate Lower Bound PCB Load		Daily Flow >150% of previous day?	*Approximate* Upper Bound PCB Load	
						Levels predicted from regression: PCBs (µg/kg) = 28275 x [Q (cfs) ^ -1.184]			Same except August centrifuge sample concentration assigned for 2 days when daily flow increased by >150% (bold)	
Flow Station Auburn	Date	Daily Flow Q (cfs)*	Daily Flow Q (l/d)	Sediment Load (kg/day)	SSC (mg/L)	Total PCB (µg/kg)	PCB Load (g/d)		Total PCB (µg/kg) **	PCB Load (g/d)
12113000	1/17/1975	**5140**	12575466432	1413903	112	1.1	1.62	Y	**62**	87.7
12113000	1/18/1975	**9480**	23193661824	7808086	337	0.6	4.32	Y	**62**	484
12113000	1/19/1975	9210	22533082848	7162821	318	0.6	4.10		0.6	4.10
12113000	1/20/1975	9270	22679878176	7302671	322	0.6	4.15		0.6	4.15
12113000	1/21/1975	9200	22508616960	7139707	317	0.6	4.09		0.6	4.09
12113000	1/22/1975	8520	20844936576	5692763	273	0.6	3.57		0.6	3.57
12113000	1/23/1975	6160	15070987008	2283670	152	0.9	2.10		0.9	2.10
12113000	1/24/1975	5800	14190215040	1942319	137	1.0	1.92		1.0	1.92
12113000	1/25/1975	4980	12184012224	1303216	107	1.2	1.54		1.2	1.54
12113000	1/26/1975	4020	9835286976	763586	77.6	1.5	1.17		1.5	1.17
12113000	1/27/1975	3100	7584425280	415800	54.8	2.1	0.86		2.1	0.86
12113000	1/28/1975	2380	5822881344	234637	40.3	2.8	0.67		2.8	0.67
12113000	1/29/1975	2670	6532392096	299240	45.8	2.5	0.74		2.5	0.74
12113000	1/30/1975	2480	6067540224	255722	42.1	2.7	0.69		2.7	0.69
12113000	1/31/1975	2240	5480358912	207128	37.8	3.1	0.63		3.1	0.63
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮
12113000	11/16/1975	2730	6679187424	313960	47.0	2.4	0.76		2.4	0.76
12113000	11/17/1975	2720	6654721536	311473	46.8	2.4	0.76		2.4	0.76
12113000	11/18/1975	2160	5284631808	192424	36.4	3.2	0.61		3.2	0.61
12113000	11/19/1975	1780	4354928064	131986	30.3	4.0	0.53		4.0	0.53
12113000	11/20/1975	1520	3718814976	98835	26.6	4.8	0.48		4.8	0.48
12113000	11/21/1975	1390	3400758432	84523	24.9	5.4	0.45		5.4	0.45
12113000	11/22/1975	1270	3107167776	72562	23.4	6.0	0.43		6.0	0.43

						Approximate Lower Bound PCB Load		Daily Flow >150% of previous day?	*Approximate* Upper Bound PCB Load	
						Levels predicted from regression: PCBs (µg/kg) = 28275 x [Q (cfs) ^ -1.184]			Same except August centrifuge sample concentration assigned for 2 days when daily flow increased by >150% (bold)	
Flow Station Auburn	Date	Daily Flow Q (cfs)*	Daily Flow Q (l/d)	Sediment Load (kg/day)	SSC (mg/L)	Total PCB (µg/kg)	PCB Load (g/d)		Total PCB (µg/kg) **	PCB Load (g/d)
12113000	11/23/1975	**1370**	3351826656	82448	24.6	5.5	0.45		**62**	5.11
12113000	11/24/1975	**2290**	5602688352	216689	38.7	3.0	0.64	Y	**62**	13.4
12113000	11/25/1975	**5130**	12551000544	1406796	112	1.1	1.61	Y	**62**	87.2
12113000	11/26/1975	4850	11865955680	1217937	103	1.2	1.49		1.2	1.49
12113000	11/27/1975	5300	12966920640	1531133	118	1.1	1.69		1.1	1.69
12113000	11/28/1975	4150	10153343520	825134	81.3	1.5	1.21		1.5	1.21
12113000	11/29/1975	2650	6483460320	294440	45.4	2.5	0.78		2.5	0.78
12113000	11/30/1975	**2750**	6728119200	318974	47.4	2.4	0.76		**62**	19.8
12113000	12/1/1975	**4900**	11988285120	1250251	104	1.2	1.51	Y	**62**	77.5
12113000	12/2/1975	**10400**	25444523520	10333500	406	0.5	5.12	Y	**62**	640
12113000	12/3/1975	11600	28380430080	14484749	510	0.4	6.31		0.4	6.31
12113000	12/4/1975	11000	26912476800	12278650	456	0.5	5.70		0.5	5.70
12113000	12/5/1975	11400	27891112320	13718993	493	0.4	6.10		0.4	6.10
12113000	12/6/1975	11200	27401794560	12983910	474	0.5	5.90		0.5	5.90
12113000	12/7/1975	11200	27401794560	12983910	474	0.5	5.90		0.5	5.90
12113000	12/8/1975	10400	25444523520	10333500	406	0.5	5.12		0.5	5.12
12113000	12/9/1975	9820	24025502016	8680675	361	0.5	4.61		0.5	4.61
12113000	12/10/1975	9000	22019299200	6688885	304	0.6	3.94		0.6	3.94
12113000	12/11/1975	7380	18055825344	3766132	209	0.7	2.80		0.7	2.80
12113000	12/12/1975	5880	14385942144	2014762	140	1.0	1.96		1.0	1.96
12113000	12/13/1975	4020	9835286976	763586	77.6	1.5	1.17		1.5	1.17
12113000	12/14/1975	2840	6948312192	342213	49.3	2.3	0.79		2.3	0.79
12113000	12/15/1975	2690	6581323872	304093	46.2	2.5	0.75		2.5	0.75
12113000	12/16/1975	3040	7437629952	397942	53.5	2.1	0.85		2.1	0.85

						Approximate Lower Bound PCB Load		Daily Flow >150% of previous day?	*Approximate* Upper Bound PCB Load	
						Levels predicted from regression: PCBs (µg/kg) = 28275 x [Q (cfs) ^ -1.184]			Same except August centrifuge sample concentration assigned for 2 days when daily flow increased by >150% (bold)	
Flow Station Auburn	Date	Daily Flow Q (cfs)*	Daily Flow Q (l/d)	Sediment Load (kg/day)	SSC (mg/L)	Total PCB (µg/kg)	PCB Load (g/d)		Total PCB (µg/kg) **	PCB Load (g/d)
12113000	12/17/1975	2780	6801516864	326597	48.0	2.4	0.77		2.4	0.77
12113000	12/18/1975	2370	5798415456	232595	40.1	2.9	0.66		2.9	0.66
12113000	12/19/1975	2090	5113370592	180144	35.2	3.3	0.60		3.3	0.60
12113000	12/20/1975	1770	4330462176	130593	30.2	4.0	0.53		4.0	0.53
12113000	12/21/1975	1760	4305996288	129211	30.0	4.1	0.52		4.1	0.52
12113000	12/22/1975	1950	4770848160	157169	32.9	3.6	0.56		3.6	0.56
12113000	12/23/1975	1930	4721916384	154055	32.6	3.6	0.56		3.6	0.56
12113000	12/24/1975	2070	5064438816	176734	34.9	3.4	0.59		3.4	0.59
12113000	12/25/1975	2490	6092006112	257898	42.3	2.7	0.70		2.7	0.70
12113000	12/26/1975	**3650**	8930049120	606050	67.9	1.7	1.04		**62**	37.6
12113000	12/27/1975	**6800**	16636803840	2994434	180	0.8	2.46	Y	**62**	185
12113000	12/28/1975	4770	11670228576	1167472	100	1.2	1.46		1.2	1.46
12113000	12/29/1975	4390	10740524832	947784	88.2	1.4	1.30		1.4	1.30
12113000	12/30/1975	5160	12624398208	1428194	113	1.1	1.62		1.1	1.62
12113000	12/31/1975	4510	11034115488	1013683	91.9	1.3	1.35		1.3	1.35
Annual Totals			1783511856835 liters	217683 mT	122 mg/L	1.3 µg/kg	279 g		10.4 µg/kg	2270 g

*= Bold in this column indicates mean daily flow that is ≥150% of the mean daily flow of the previous day.

**= Bold in this column indicates contaminant concentrations measured in suspended sediment collected by centrifuge in August, 2008. These concentrations were used to *approximate* upper-bound annual loads.

Q = mean daily flow.

SSC = suspended solids concentration.

(See Appendix A for definitions of units of measurement.)