Sediment transport and contaminant loading to the Lower Duwamish Superfund Site from the Green River: Application of innovative sampling technologies to verify model predictions.

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Abstract

In 2001, state and federal authorities designated approximately 5 miles of the Lower Duwamish Waterway (Seattle, Washington) as a cleanup site (Figure 1). A sediment transport model (STM) was subsequently developed to predict the fate of suspended sediments and bed load entering the waterway from the upstream Green River and local sources such as stormwater discharges. A bed composition model (BCM) was also developed. It used chemical concentrations thought to represent sediment from ongoing sources to calculate bottom sediment quality in the cleanup site after remedial actions are taken.

Figure 1. The Lower Duwamish Waterway cleanup site and Green River showing sites where suspended sediment was collected using centrifuges (and sieves) and where sediment tracers were released.

In 2008-2009, the Washington State Department of Ecology (Ecology) conducted a study designed to measure contaminant concentrations and estimate contaminant loading associated with suspended Green River sediments. Samples were collected using continuous-flow centrifuges and sieves deployed in the field. Samples were analyzed for polychlorinated biphenyls (PCBs), organic carbon, arsenic, polychlorinated dibenzo- dioxins and furans (PCDD/F), and polycyclic aromatic hydrocarbons (PAHs). Results aided development of final BCM input values.

A companion study used sediment tracer particles to evaluate STM transport and fate predictions. Tracer particles were released near the upstream site boundary and recovered from river water and bedded sediments up to two months later. Recovery of tracers throughout the waterway supported STM predictions.

Introduction

The STM predicted that approximately 80% of the sediment load to the cleanup site enters as suspended sediments from the Green River. Therefore, this was expected to be the main source of particle-associated contaminants. Yet only limited concentration data for contaminants in upstream whole water and bedded sediments were available for use as draft BCM input values. Contaminant concentrations associated with suspended sediment had not been measured.

The STM also divided the cleanup site into several river reaches, each with different sediment accumulation and erosion characteristics. Incoming sand-sized particles were predicted to accumulate in the upstream reach containing a vessel-turning basin. It predicted that approximately 50% of incoming fine suspended sediments would accumulate within the cleanup site and 50% would pass through the site.

Ecology conducted the these studies to provide concentration data on which to base BCM input values and to test transport and fate predictions.

Objectives

- Measure total PCBs, arsenic, PCDD/F, and PAH concentrations in associated with suspended Green River sediments
- Measure contaminant concentrations for different particle-size fractions of suspended sediment
- Estimate contaminant loads associated with incoming suspended Green River sediments
- Evaluate short-term patterns of transport and deposition of sand-sized particles and fines
- Determine if the STM is consistent with observed movement and fate of released particles

Methods

Loading Study. River water was pumped through continuous-flow centrifuges and sieves, in which suspended sediment was collected (Figures 2-7). This occurred on 7 occasions, representing a variety of flows, between July 2008 and January 2009. Standard methods (EPA 8082, 200.8, 1613B, and 8270 SIM) were used to analyze different size classes of suspended sediment (Figure 8) and quality control samples. Daily loads were derived from concentrations and mean daily flows. A range of *approximate* annual loads was calculated using regression equations between contaminant concentrations and mean daily flows, assuming high concentrations were associated with the early phase of all high-flow events.

Tracer Study. Properties of native sediment were used as specifications for manufacturing two 100 kg batches of fluorescent/magnetic sediment tracer particles (Table 1). A red batch had settling velocities similar to native sands and a yellow-green batch was similar to fine native silts (Figure 9). Tracers were released on February 13, 2010 near the southern turning basin on an outgoing tide (Figure 10).

More than 200 samples were collected to recover tracer particles. Recovering tracers from the water column involved filtering water samples, dragging magnets, and sampling fixed-location magnets (Figure 11). Recovering tracers that had settled to the bottom involved using common grab samplers (e.g., Ponar) to collect surface sediment samples from locations chosen subjectively and randomly throughout the waterway. Sampling occurred on the day of release, after 1 week, 1 month, and 2 months.

Tracers in the samples were concentrated using a magnetic field, counted and sized using epifluorescence microscopy. Mass of each tracer in samples was calculated from estimated particle volume and density. Patterns of presence/absence, mass, and particle size were compared to STM predictions.

Figure 2. Suspended sediment sampling location (pump in water).

Figure 3. View inside trailer housing continuous-flow centrifuges.

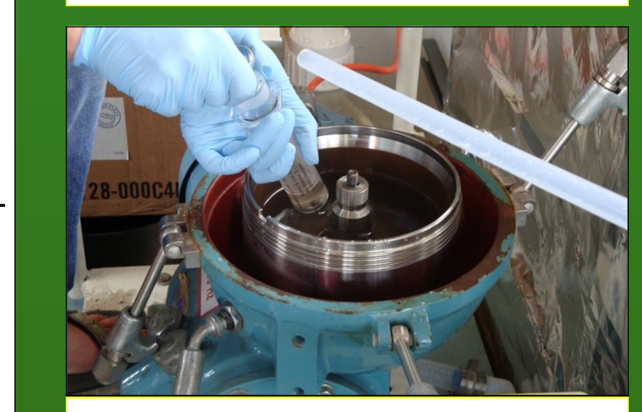

Figure 4. Removing overlying water.

Figure 5. View inside centrifuge bowl after removing overlying water.

Figure 6. Flow-through sieving station. River water was pumped through 1-2 stainless steel sieves for timed intervals until centrifuge sampling ended.

Figure 7. Collecting sediment from sieves. Suspended sediments collected on sieves were rinsed with site water into pre-cleaned glass jars.

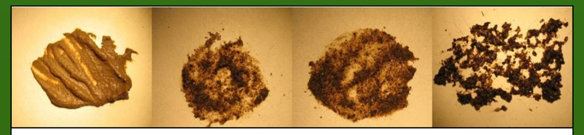

Figure 8. Size classes of suspended river sediments. Left to right:

- centrifuged sediment (all sizes)
- >63μm diameter particles (all sands)
- 63-250 μm (finer sands)
- >250 μm (medium-to-coarse sands)

Table 1. Target and actual properties of sediment tracers, with images of indivdual particles and pre-wet batches ready for release.

Property	Size Class	Sediment Specification	Tracer
Density (g/cm^3)	Sand	2.58	2.51
	Silt	1.20	1.21
Settling Velocity (m/sec)	Sand	0.006 - 0.040	0.002 - 0.029
	Silt	0.00013 - 0.00024	0.000037 - 0.001188
Particle Size (um) Range (median)	Sand	156	73 - (128) - 248
	Silt	45	21 - (50) - 79
Fluorescent	Sand	Negligible	Yellow-Green
	Silt		Red
Magnetic	Sand	Uncommon	Yes
	Silt		

Figure 9. Target and actual properties of sediment tracers, with images of indivdual particles and pre-wet batches ready for release.

Figure 10. Release of yellow-green sediment tracers, representing native silts, to form subsurface plume.

Figure 11. Left to right: Magnet samplers before being deployed, with silt tracers, and tracer recovery.

Loading Study Findings

- Organic contaminant concentrations associated with suspended Green River sediment were measured and found to vary with season, mean daily flow, storm-related discharges, and phase of high-flow events. Maximum concentrations in August, caused in part by stormwater discharges early in the sampling event, were often >10X the concentrations measured during winter months (Figure 12).
- Arsenic in suspended sediment was not as variable as organic contaminants (Figure 12).

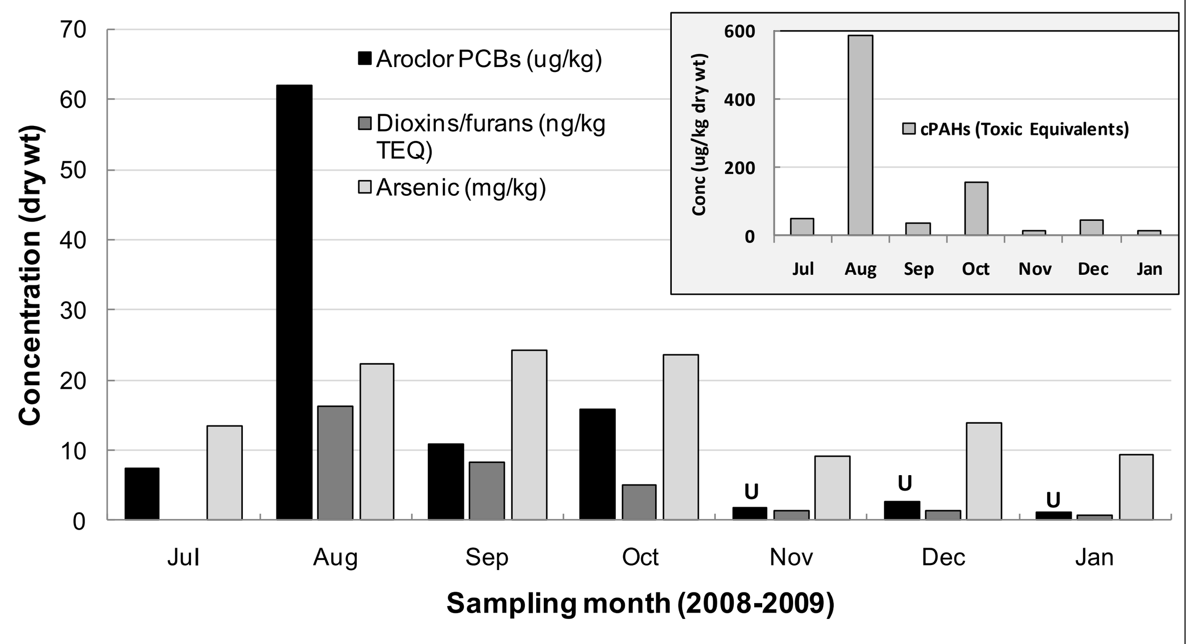

Figure 12. Contaminant concentrations in suspended Green River sediment collected by pumping water through continuous-flow centrifuges.

- Contaminant concentrations in suspended sediment were similar to or greater than those in upstream bedded sediments (Table 2). Concentrations measured in centrifuge samples, and those calculated for the suspended fines fraction only, were usually greater than the concentrations measured in sieved sediment samples (results not shown here). This suggests sedimentary loss of larger, less contaminated particles.
- Contaminant concentrations in suspended sediment were often lower than those calculated from concentrations in whole water samples normalized to total suspended solids (TSS, see Table 2). This suggests contaminants are also present in dissolved or colloidal form.
- Contaminant concentrations associated with suspended sediments, measured or derived load estimates, were compared to those for upstream water and bedded sediment, and were, in many respects, similar to draft BCM input values (Table 2).

Contaminant (dry weight)		Samples collected upstream of the Lower Duwamish Waterway site: Suspended Sediment			Bedded Sediment		Input Values: Green River Sediment	
		Measured [1]	*Calculated* [2]	*Calculated* from whole water [3]	LDWG [4]	Ecology [5]	Draft [6]	Final [7]
Total PCBs (μg/kg)	Min	1.2 U	1.3	2.8	0.6	2.3	20	5
	Means	14.5 (6.1)	-	49	18	7	50	35
	Max	62.1 J	23.6	163	140	22	140	80
PCDD/Fs (ng TEQ/kg)	Min	0.83	0.8	-	1.1	0.07	2	2
	Means	6.36 (3.22)	-	-	1.15	0.48	5	4
	Max	16.2 M	5.7	-	1.2	2.25	10	8
cPAH (μg TEQ/kg)	Min	13.1 J	12	22U	9	0.9	50	40
	Means	143.5 (57.5)	-	140	51	19.3	170	70
	Max	588	180	408	64.4	235	400	270
Arsenic (mg/kg)	Min	9.2	8	0.5	3.3	3.7	7	7
	Means	16.6 (15.4)	-	37	7	6	10	9
	Max	24.3	14.8	133	22	15	15	10

Means = arithmetic (geometric)

[1] Present study.

[2] Present study, from ***approximate*** annual loads.

[3] King County Department of Natural Resources and Parks, 2009. Personal communications.

[4] Lower Duwamish Waterway Group, 2007. Remedial Investigation, November Draft.

[5] Washington Department of Ecology, 2009. Technical memorandum on sediment sampling and analysis for Lower Duwamish Waterway Risk Assessment. Prepared by Ecology and Environment, Inc., Bellevue, WA.

[6] Lower Duwamish Waterway Group, 2008. Personal communications.

[7] Lower Duwamish Waterway Group, 2010. Feasibility Study, October Draft. Prepared for the U.S. EPA and Washington State Department of Ecology by ENSR and AECOM (under contract to LDWG).

Tracer Study Findings

- Sand tracers 1) remained within the Lower Duwamish Waterway, 2) accumulated mostly within a few hundred meters of the southern turning basin, 3) decreased in mass from the upper river reach, to the lower reach, to the middle reach, and 4) were size-sorted within 1-2 km of the release site (data not shown here).
- Silt tracer results were qualitative due to losses during sampling and analytical limits. However, spatial and temporal distributions of silt tracers recovered in all sample types were consistent with the STM predictions:
  - Silt-sized particles can pass rapidly through the cleanup site, as evidenced by silt tracers recovered in filtered water and towed magnet samples collected near the West Waterway (and at other downstream reach locations) within 4 hours of release time.
  - Suspended silts can be deposited throughout the cleanup site, at least temporarily, as shown by presence of silt tracers in surface sediment samples collected from all river reaches (Figure 13).
  - Deposited silts can easily be resuspended, as indicated by silt tracers accumulated on fixed magnets during the second month following their release.
  - Silt particles can be transported and temporarily deposited upstream of the release site during flood tides, as evidenced by their presence in surface sediment samples collected 1 week after release (Figure 13).

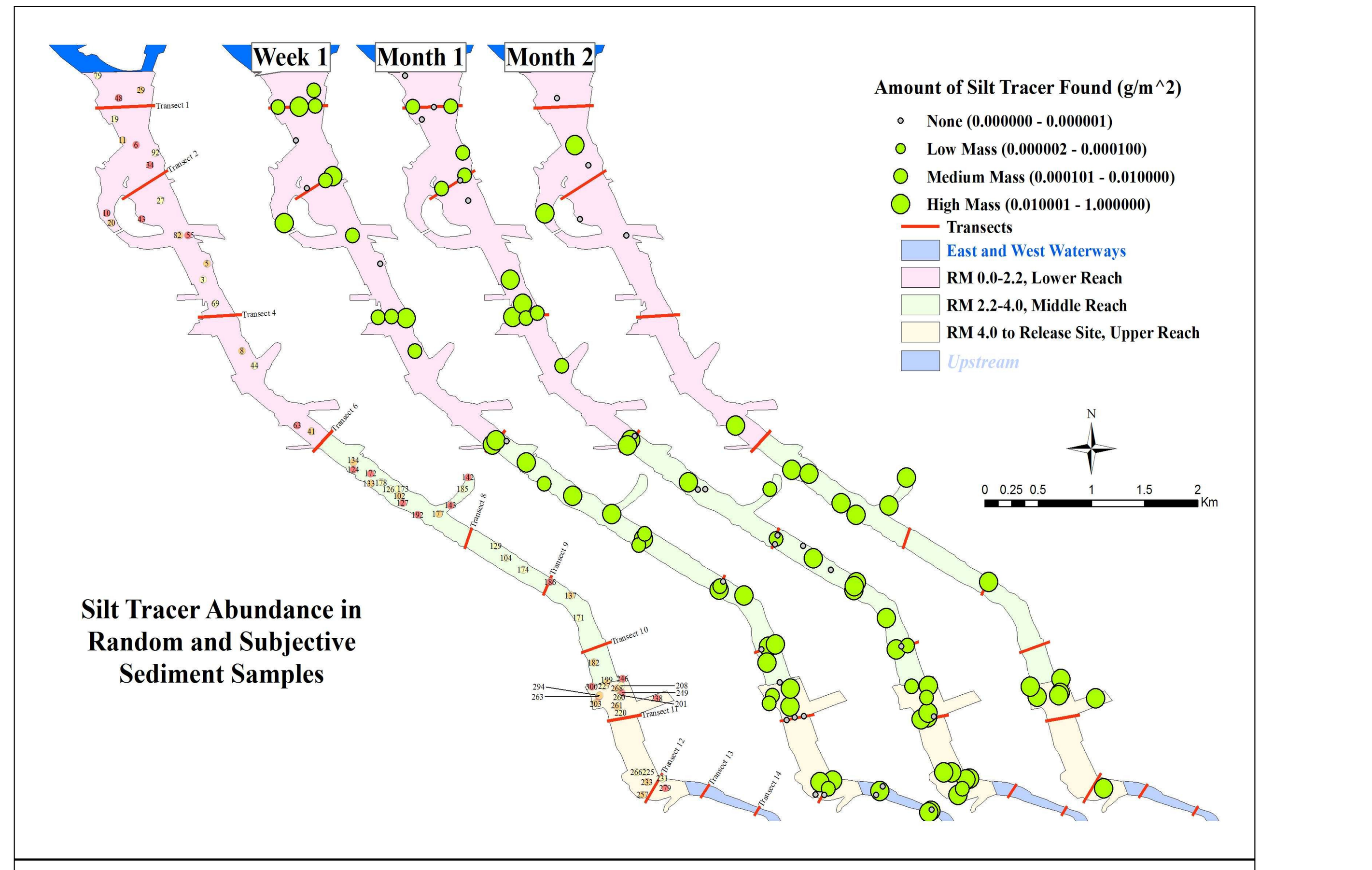

Figure 13. Sampling sites (left) and recovery of silt-sized sediment tracers from Lower Duwamish Waterway surface sediments (right) after release into the southern turning basin.

Recommendations

Loading Study

- Continuous-flow centrifugation efficiently removed suspended sediment from river water and should be used when hydrophobic contaminant concentrations in whole water samples are below detection limits.
- Results should be used as a strong line of evidence for choosing suitable contaminant concentrations as inputs to the bed composition model (BCM) [Note: results were useful in developing final BCM values].
- Accurate estimates of annual contaminant loading from suspended Green River sediments should be developed. More sampling and analysis should be conducted to better understand the sediment-bound contaminant concentrations that are mobilized during all types and phases of high-flow events.
- Future contaminant loading studies, especially where the majority of the annual sediment load occurs episodically, should consider the potential import-ance of measuring suspended solids concentration (SSC), and not TSS.

Tracer Study

- Maximize the mass of tracers manufactured and released in order to increase the probability of the tracers being recovered from the environment, especially from a large and complex study site like the estuarine Lower Duwamish Waterway.
- Future sediment tracer studies should be designed to provide more quantitative results:
  - Surface sediment sampling methods should be revised or developed (e.g., magnet sampler) to eliminate losses of recently-settled silt tracers.
  - Analytical protocols should be automated to allow counting and sizing of all fluorescent/magnetic tracer particles in recovery samples.
- Use sediment tracer technology, and the lessons learned from the present study, in other studies (e.g., identify upland sources of contaminated sediment, measure rates of natural burial, assess best management practices to minimize erosion).

Visit our Web sites:

Poster — www.ecy.wa.gov/biblio/1003068.html

Loading Study — www.ecy.wa.gov/biblio/0903028.html

Tracer Study — www.ecy.wa.gov/biblio/0903048.html

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