Evaluation of Stormwater Suspended Particulate Matter Samplers

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Cover photo: Deployment of samplers in a City of Tacoma stormwater pipe.

Evaluation of Stormwater Suspended Particulate Matter Samplers

by

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Waterbody Numbers:

Thea Foss Waterway: WA-10-0030
Spokane River: WA-57-1010

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Abstract

During 2011 – 2012, the Washington State Department of Ecology (Ecology) tested its prototype Hamlin sampler for its capabilities to collect stormwater suspended particulate matter (SSPM). The Hamlin sampler was tested at three field sites (two in Tacoma and one in Spokane) for three timeframes at each site.

Concurrent with the prototype testing, a comparison study was conducted to evaluate the Hamlin sampler relative to two other in-line sampling devices: the commonly used Norton bottle trap developed by Ecology in 1996 and the new prototype Fuller sampler developed by the City of Tacoma.

Comparison of the Hamlin sampler to the Norton and Fuller samplers was conducted at the field site 237A in Tacoma for three sampling timeframes. For two storm events at the same site, stormwater was also sampled by a mobile continuous-flow centrifuge unit and an in-situ, real-time particle size analyzer. SSPM samples collected by the three samplers and the centrifuge were analyzed for total organic carbon (TOC), percent solids, metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

This report presents the first comparative analysis of these three stormwater in-line sediment samplers. Categories evaluated include physical ease of use, mass accumulation of SSPM, representativeness of SSPM size distribution, and contaminant chemistry compared to the centrifuge SSPM material. Advantages and disadvantages were identified for each sampler based on the experiences of this study. No single device was superior in all categories; however, with some design modifications the Hamlin would be best suited for SSPM contaminant monitoring. Results of the prototype testing and comparison study show that the Hamlin sampler (1) functions well in both small and large storm sewer systems and (2) captures a larger mass of SSPM in a shorter timeframe than the commonly used Norton bottle sampler.

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Introduction

Stormwater particulates, particularly the fines (≤0.062 um), are a major transport mechanism for contaminants (metals and organics) that can impair water and sediment quality in receiving waters. Traditionally, studies have been conducted to characterize contaminants in whole stormwater. But due to the regulatory focus on water quality and the relative lack of marketed particulate collection devices, few studies focused on stormwater particulates. However, there is increasing interest in monitoring stormwater suspended particulate matter (SSPM) to identify potential problems in sub-drainage systems. SSPM data are useful in providing information on extremely hydrophobic constituents such as mercury, HPAHs, DDTs, and PCBs, which have a strong affinity for sediments but are poorly soluble and often not detected in whole-water samples.

Although stormwater flows can suspend very large particles at times, nearly two thirds of the particulate mass found in stormwater consists of particles in the clay to silt range (0.001 – 0.062 um), (Pitt and Bissonnette, 1984). The predominance of small particles in stormwater is noted by others nationally (Brown et al., 2011), and it has been widely reported that these fine-grained particles are associated with higher contaminant concentrations (SAIC, 2012). As such, the focus of this study was to characterize the finer fractions of SSPM captured by various devices that would be used for contaminant tracing in urban stormwater systems.

Stormwater and SSPM monitoring results within any given drainage are often highly variable; large ranges for both particulate diameter and contaminant chemistry concentrations exist. Part of the variability may be explained by season, storm size, or human activity. Variation may also be explained by the biases imparted by the devices used to capture stormwater or stormwater particulates. Methods used to collect stormwater particulates have included: grab samples of catch basin bottom sediments, filtering stormwater in the field and extracting the solids, centrifuging stormwater in the field, or using passive capture devices mounted in-line to passively sample the suspended particulates.

This study was undertaken to conduct a comparison study between a new prototype sampler (Hamlin) and two other in-line SSPM sampling devices (Norton and Fuller). Comparisons of the mass, size distribution, and chemistry of the captured particulates from each method were then compared to a continuous-flow centrifugation sampler as the “true” stormwater sample. This was done to estimate the bias imparted by each SSPM sampling device. Filtration of stormwater, another method to capture SSPM (SAIC, 2012), was not included due to budgetary constraints.

Historical Background

In 1988, the Washington State Department of Ecology (Ecology) developed a simple low-cost sediment sampler as part of a sediment flux study in a marine environment, the Thea Foss Waterway (Norton, 1990). The sampler consisted of a tall straight-sided glass cylinder with a collection area of 64 cm^2 and a height-to-width ratio of 5. This design provided adequate sampler storage for fine sediment in a submerged marine environment with moderate current velocity.

Years later, stormwater particulates were suspected of re-contaminating sediment clean-up efforts; therefore, an effective sampler was needed to sample entrained sediment from a municipal stormwater system.

In the mid 1990s, Ecology conducted a literature review for stormwater sediment sampler technologies (Barnard and Wilson, 1995) and designed a device (see Figure 1) to capture stormwater particulates from conveyance systems for contaminant source tracing (Wilson and Norton, 1996).

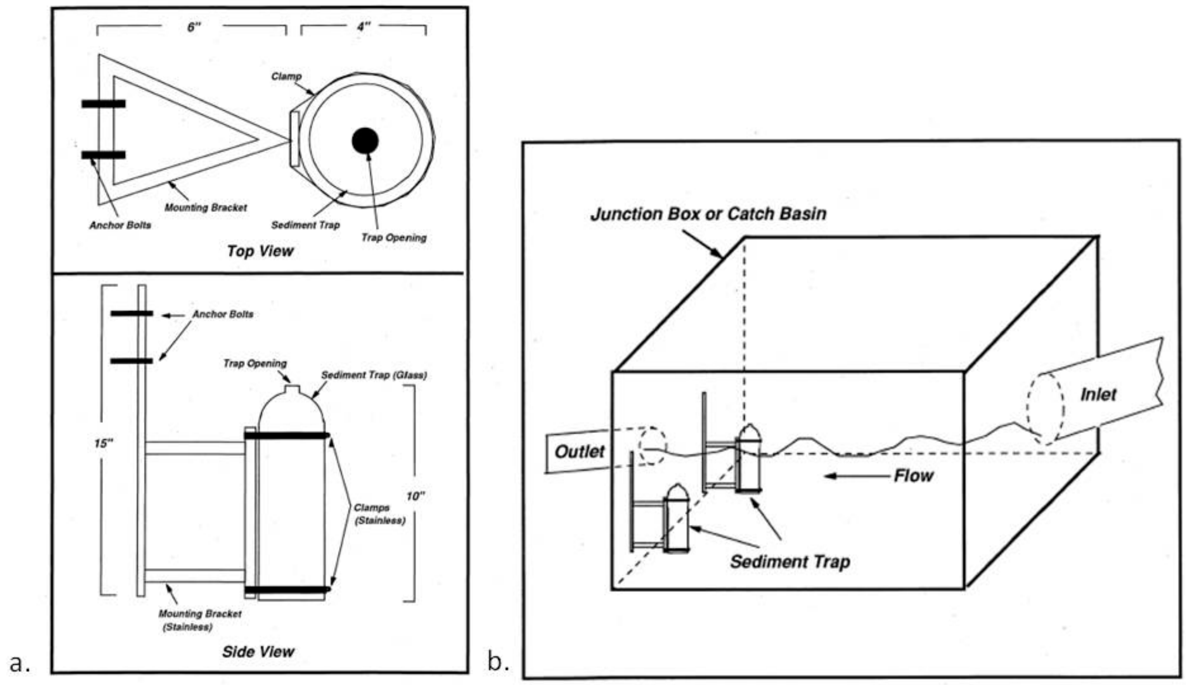

Figure 1. Norton SSPM bottle sampler and deployment (Wilson and Norton, 1996).

For the stormwater environment, Wilson and Norton encased the upright glass bottle in protective steel and added mounting brackets to position it in the catch basin. As the water level submerges the bottle opening, SSPM falls in the quiescent interior and over time displaces the water.

Ecology and local municipalities have used this bottle sampler extensively for characterization and contaminant source identification. Since 1996, this sampler has been modified and known by several names including: modified Ecology bottle sampler, domed top bottle sampler, and the modified Norton stormwater sediment bottle sampler. For simplicity, this sampler will be referred to as the Norton bottle trap throughout this report.

Need for a new device

Despite more than a decade of use and modifications, the Norton bottle trap has several drawbacks for stormwater contaminant monitoring.

- The length of time needed to collect enough SSPM for contaminant analysis can range from 1 to 12 months to collect 50 to 100 dry grams of stormwater sediment (Wilson and Norton, 1996; Norton, 1997 and 1998; and City of Tacoma - Dana de Leon, personal communication, 2011; and SAIC, 2010).
- Current sampler design requires anchoring the devices into the concrete structure of the stormwater system, which not every municipality will allow (Ted Hamlin, personal communication, 2011).
- The size fraction of particulates sampled by the Norton bottle sampler is unknown. Data are needed to determine whether the collected solids are representative of all the suspended stormwater particles entrained in the stormwater flow (Rick Fuller, personal communication, 2011; Hafner, 2011).

An SSPM sampling device was needed to more rapidly capture enough material for contaminant source tracing. Around 2007, two new in-line devices (Hamlin and Fuller samplers) were separately designed, without the designers' knowledge of each other. The criteria driving new designs included:

- Improved rate of particulate capture compared to Norton samplers
- Low cost
- Easy use and cleaning
- Resistant to fouling by debris

Both resultant samplers are low profile, flow-over SSPM sampling devices made of stainless steel.

The Hamlin sampler was developed by Ted Hamlin with Ecology's Urban Waters Program for use in Spokane. It can be tethered or anchored without the use of bolts to secure it to the pipe bottom. The Fuller sampler was developed by Rick Fuller, formerly with the City of Tacoma, in partnership with the City of Vancouver, BC. The Fuller sampler was designed to be bolted to the pipe bottom. A more detailed description of the sampling devices can be found in the Study Design section below and in the Quality Assurance (QA) Project Plan for this project (Osterberg and Lubliner, 2011).

Project Objectives

This study consisted of two principal elements: (1) performance evaluation of the Hamlin prototype sampler under a variety of field conditions and (2) comparison of the Hamlin prototype sampler and other known methods for capturing SSPM. The comparison study evaluated three in-line passive capture devices: Norton bottle trap sampler, the Hamlin prototype sampler and the Fuller prototype sampler).

On two occasions, the stormwater was also sampled by continuous-flow centrifugation and monitored in real-time using a Laser In-Situ Scattering and Transmissometry particle-size-distribution analyzer (LISST) to represent the "true" physical and chemical characteristics of the SSPM for comparison to each in-line sampling device's material.

The SSPM from each in-line sampler and two centrifuges were analyzed for physical and chemical parameters:

- Physical
  - mass
  - percent solids
  - grain size
  - particle size distribution (by the LISST)
- Chemical
  - total organic carbon (TOC)
  - metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc)
  - polycyclic aromatic hydrocarbons (PAHs)
  - polychlorinated biphenyls (PCBs)

Study Design

Site Selection

Prototype testing of the Hamlin sampler was conducted at three stormwater pipe manhole locations: two sites (237A and FD3) in Tacoma and the third site (UnionLPT) in Spokane. Sampling for the methods comparison study was conducted at only one site in Tacoma (237A).

The City of Tacoma assisted in site selection to be sure the sites had uni-directional flow, were above tidal influence, could accommodate multiple sampler devices, and were safe for personnel. Preference was given to manholes or drainages where pervious stormwater particulate results were available for comparison to results in this study. The sites also provided for a range in land use, drainage area size, and pipe gradients. The City of Spokane granted Ecology access to the UnionLPT site for ongoing stormwater monitoring.

Table 1 and Figure 2 describe the three field locations for the stormwater particulate study. Appendix A contains detailed maps of each of the drainage basins sampled. Table 1 also lists the known characteristics of the stormwater drainage system.

Table 1. Site descriptions.

Site	237A[1]	FD3 [1]	UnionLPT
Associated Outfall	West Twin	230	Erie CSO 34
City	Tacoma	Tacoma	Spokane
Estimated Contributing Drainage size	1,792 acres[2]	400 acres[2]	109 acres
Manhole ID Accessed	6764574	6767780	100 feet south of Trent Ave on Erie St
Pipe Diameter	72 inches	54 inches	24 inches
Primary Land Uses	Residential, Commercial, and Industrial	Commercial and Residential	Industrial, Commercial, Residential
SSPM Samplers Deployed	Norton, Fuller, Hamlin, Centrifuge, LISST	Norton and Hamlin	Hamlin

[1] City of Tacoma, 2011.
[2] Personal communication, Dana de Leon, City of Tacoma, October 2012.

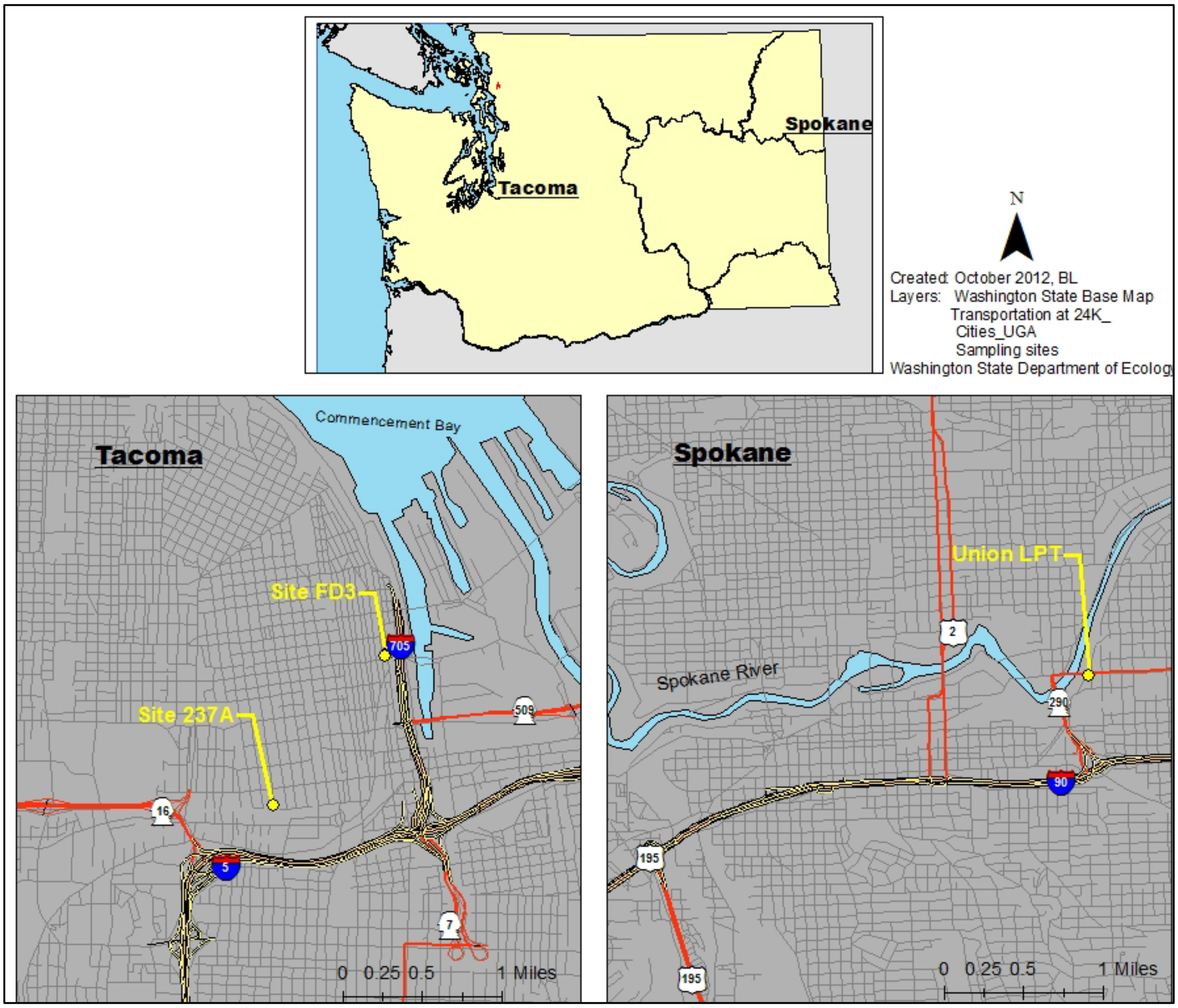

Figure 2. Location of three sites sampled for the stormwater sediment sampler device comparisons.

Tacoma monitoring sites (237A and FD3)

The drainage areas to the City of Tacoma Thea Foss sampling sites (237A and FD3) are shown in Appendix A. For site 237A, the drainage area downstream of this manhole (to the west and north) was not sampled as part of this study. Site 237A is upstream of the West Twin 96er outfall. FD3 (new) is the manhole designation that was monitored by this study which is associated with outfall 230. In Appendix A, Figure A-1, the sub-basin draining to outfall 230 (sampled at manhole FD3) is denoted as FS-05 which references Tacoma's basin management number.

Spokane monitoring location (UnionLPT)

Stormwater sampled in Spokane was from the Union drainage area which is part of the larger CSO34 basin. UnionLPT is located on the south side of the Spokane River near river mile 76, just south of Trent Avenue, State Route 290. Union basin is approximately 109 acres, composed of 325 parcels; it is predominantly an industrial area in the City of Spokane. This basin has a combination of piped stormwater infrastructure and disconnected infiltration areas. The major geologic unit is flood deposit and gravel, and it is relatively flat, with a decided drop in elevation along Springfield Road.

The UnionLPT sampling site is the first manhole access upstream of the outfall. The manhole is in the roadway on Trent Avenue. The manhole depth is approximately 4 feet, and the Hamlin sampler can easily be lowered down and retrieved without requiring entry into the manhole.

In-line Sampler Descriptions

Hamlin

The Hamlin sampler is constructed using 14-gage solid stainless steel and has two distinct chambers. The top piece or “tongue” deflects water flowing along the pipe up the ramp and to the ¼-inch wide slots where stormwater can fall through to the upper chamber. Dimensions are 21.5L x 9.25W x 4H inches. Figure 3 shows the Hamlin device and the two chambers.

Figure 3. Hamlin SSPM sampler.

Assembled (right), Upper Chamber (top left), and Lower Chamber, with baffles, tray, and exit ports (bottom left).

The back of the sampler has a raised lip perpendicular to the direction of flow that functions as an obstruction to slow the stormwater flow and improve intake through three ¼-inch wide slots. Once in the second chamber, the water velocity slows and the water must switch directions to move forward in the device to a second set of ¼-inch slots. Once in the bottom chamber, the water reverses flow direction again and passes over a series of six baffles – vertical barriers affixed to the bottom of the sampler – that further slow the flow and create pockets of low turbulence where particulates can settle and not be easily re-suspended. Small ports at the rear of the lower chamber allow stormwater to exit the sampler.

The Hamlin sampler's low profile is intended to resist fouling and accumulating large debris. The top "tongue" piece, the middle divider, and the bottom tray and baffles are removable so that the particulates can be removed. The parts are easy to reassemble and do not require tools. The weight (approximately 25 lbs) is enough to withstand low flows (e.g., at the Spokane field location); however, for moderate to large flows (e.g., at Tacoma field locations), the rails along the sides can be held to the bottom of the concrete pipes using metal flanges and expansion bolts.

Fuller

The Fuller sampler is constructed of (1) stainless steel grating, spaced on ½-inch centers, on the top section and (2) solid 12-gage stainless steel for the bottom and sides. The frame (shown in Figure 4) allows the device to be deployed at various heights such that baseflow sampling can be avoided by raising the height of the sampler by approximately 3 inches. Dimensions of the Fuller device are 21.5L x 9.75W x 4H inches. The steel plate to restrict flow was a mid-study adaptation. Unfortunately, the frame does not fit into some manholes and, therefore, had to be tipped during retrieval, which can cause captured SSPM to be spilled.

The Fuller sampler has a bottom curvature that allows it to sit flush on the bottom of the stormwater pipe, and it can be bolted to the floor of the concrete pipe using expansion bolts. The top sloped ramp is made of stainless steel grating, which slows the velocity of the stormwater but allows flow to directly enter the center. The center has a baffled tray where settling stormwater particles are held. Stormwater is allowed to flow out through the top of the sampler.

Figure 4. Fuller SSPM sampler
Assembled (right), tray access (top left), and lower chamber with baffle and tray (bottom left).

Norton

Since the mid-1990s the Norton bottle trap has been modified by Ecology, the City of Tacoma, and the City of Seattle. Modifications allow the trap to hold the bottle upright, keep the bottle in place, and use thicker steel to resist deformation. The joints added to the mounting bracket are necessary to position the bottle upright in a curved pipe versus the catch basin wall mounting. The bail was added to keep the bottle from floating away when empty. Due to breakage, glass bottles have been replaced with Teflon-lined plastic bottles. Figure 5 shows a common configuration of the Norton bottle trap.

Dimensions of the Norton trap are approximately 9.5 inches from front to back of the mounting plate and 6 inches tall. The inner diameter of the cylinder is 3.75 inches, large enough to hold a 1-liter, Teflon-lined bottle. The brackets are attached to the concrete pipes in Tacoma, using expansion bolts.

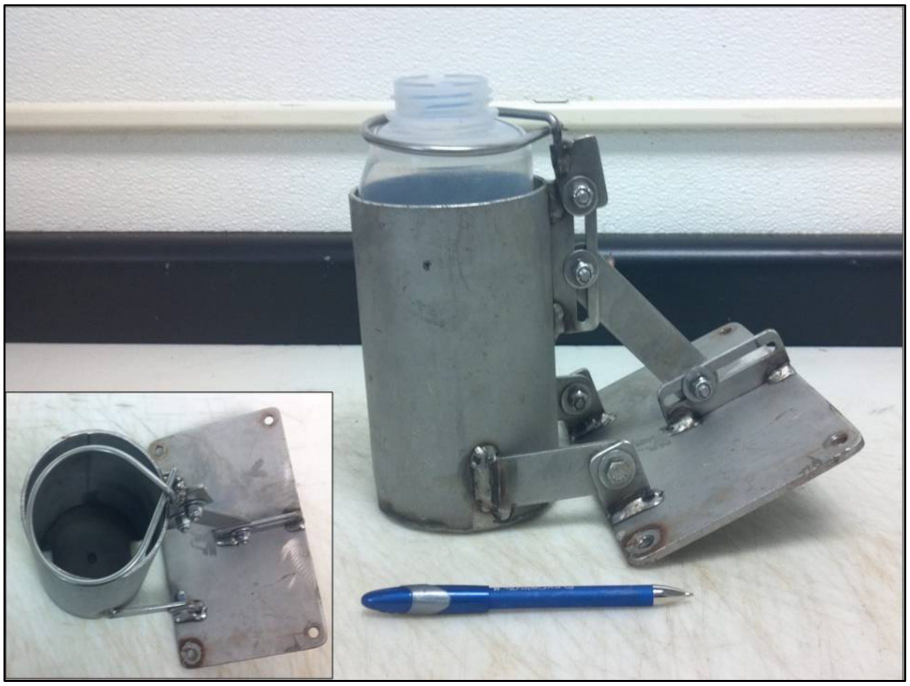

Figure 5. Modified Norton bottle trap.
Assembled (right) and top view (inset).

Measurement of "True" SSPM Characteristics

Continuous-flow centrifugation

An Ecology-owned centrifuge trailer employs two centrifuges (Alfa-Laval Sedisamp II, Model 101L), in parallel, to separate and concentrate particulates from the stormwater. Continuous-flow centrifuges were used to collect enough mass of SSPM from "whole" stormwater to measure the concentrations of contaminants. This sample was used as a reference or "true" characteristic of SSPM because it came from whole stormwater. We know from previous studies that the centrifuge captures fines when present in the water column. The assumption is that the turbulence in the stormwater pipes during a storm event provides a fully mixed water sample. For additional Ecology studies using the centrifuge for suspended particulate collection, see Seiders (1990), Yake (1993), and Gries and Sloan (2008 and 2009).

LISST

Concentrations and size distributions of in-situ suspended sediment were measured using a LISST-Streamside instrument (Sequoia Scientific, Inc.). The purpose was to evaluate the in-situ particle size distribution of the stormwater pumped from the storm pipe. The LISST measures the characteristics of laser light diffracted by suspended particles that pass by. In this study, readings from the LISST provided real-time, particle size estimations within the clay to fine sand range (2.5 to 500 um).

Methods

Sample Collection

Timing

The three SSPM samplers were used for short-term, storm event-targeted, real-world contaminant monitoring. Timing of the sampling events was based on storm events, stormwater flows, and availability of field staff and functioning equipment. Deployment and retrieval of the samplers from within the stormwater pipes required low flows and safe conditions for the City of Tacoma field crews. For this reason, periods of dry weather were targeted for deployment and retrieval of the in-line samplers. Sampling using the continuous-flow centrifuge and LISST required an active storm event and enough stormwater flow to submerge the groundwater pump.

The Norton, Hamlin, and Fuller samplers were each deployed in the City of Tacoma stormwater pipes to target one to three storm events, as shown in Table 2. The deployment timeline includes the preceding and subsequent dry period for retrieval after the event(s). The centrifuge and LISST sampling targeted two storm events, coincident with the deployment of the three in-line devices.

Table 2. Sampling dates at the Tacoma sites.

Sampling Periods	Deployed at Site FD3[1]	Deployed at Site 237A[1]	Sampling Dates[2] 2011-2012	No. of Days Sampled	Total Rainfall During Deployment (in)[3]	No. of Storm Events During Deployment[4]
#1	N, H*	N, H*, F$^{\Phi}$	Oct 6 - 17	11	0.98	1
#2	N, H	N, H, F	Oct 19 - Nov 8	20	1.69	4
#3	N, H	N, H, F	Nov 8 - 30	22	3.82	5
#4	N, H*	N, H	Dec 1 - Jan 6	36	3.06	7
#5	-	N, H, F	Feb 3 - 24	20	1.91	4
Full Length (FL)	N_{FL}	-	Oct 6 - Jan 6	89	9.55	17
	-	N_{FL}	Oct 6 - Feb 24	110	11.46	21
Centrifuge/ LISST #1	-	C, L	Feb 10 11:35 to 16:25	7 hrs	0.02	1
Centrifuge/ LISST #2	-	C, L	Feb 17 13:25 to 17:40	4 hrs	0.41	1

* Sampler lost; no results.
$^{\Phi}$ Some trapped material was lost due to tipping of sampling device.
- not applicable.
[1] Samplers (N: Norton, H: Hamlin, F: Fuller, N_{FL}: Norton Full Length, C: Centrifuge, L: LISST).
[2] Timeframes are from noon the first day until noon the last day.
[3] Based on the City of Tacoma rain gage located at the Tacoma landfill, near site 237A.
[4] Estimated using discrete storm-event criteria from the Phase I permit (Ecology, 2007).

Past experience has demonstrated that Norton bottle traps typically need to be deployed for 3 to 12 months, so it was expected that the single-event deployments might not collect sufficient material for analyses. Thus several "Full Length" Norton bottle traps were deployed for approximately 3 months to obtain time-integrated samples for comparison to the other two devices. Timeframes are shown in Table 2.

Dates for the Hamlin deployments in Spokane are shown in Table 3.

Table 3. Sampling dates using the Hamlin sampler at the Spokane site UnionLPT.

Spokane Sampling Periods	Sampling Dates[1]	Total Rainfall (in)[2]	No. of Days Sampled	No. of Storm Events during Deployment
#1	Sept 28 to Oct 3, 2011	0.16	5	1
#2	Nov 22 to 25, 2011	0.62	3	1
#3	Jan 27 to Feb 2, 2012	0.78	6	1
#4	Feb 28 to March 2, 2012	0.22	3	1

[1] Timeframes are from noon the first day until noon the last day.
[2] Estimated from the KGEG rain gage (www.wunderground.com/history/airport/KGEG/2012/04/09/DailyHistory.html).

In-line sampler deployment and retrieval

Figures 6-8 show each in-line device after retrieval. Overlying water and all SSPM solids were removed from the devices' trays, baffles, and other parts using pre-cleaned stainless steel spoons and spatulas; placed in stainless steel bowls; and covered with aluminum foil. All bowls were labeled and placed inside coolers on ice and transported to Ecology's clean room for processing. While still inside the coolers on ice, the samples were placed in the walk-in cooler and allowed to settle overnight.

Hamlin and Fuller

The initial deployment of the prototype Hamlin sampler in Tacoma proved to be instructive. As they had been during prototype development in Spokane, the two Hamlin samplers were deployed using a steel cable tether fastened to the lowest manhole ladder rung or other anchoring point. In both cases the samplers broke free of the tethers, due to the much larger flows[1] in the City of Tacoma stormwater pipes. In subsequent deployments, the Hamlin devices were bolted down in a similar manner as the Fuller and Norton devices. Additionally, the tongue piece was bolted down to prevent it from flipping up. For perspective, in the Spokane pipe the Hamlin does not require anchoring, because the flow rates are much lower[2] and the weight of the device kept it situated on the bottom of the pipe.

An estimated 30% of SSPM was lost from the prototype Fuller sampler during the first event monitored, because the device had to be tilted to fit through the manhole ring. City of Tacoma staff were more careful during subsequent retrievals to keep the devices as level as possible to prevent SSPM loss.

[1] up to 37 MGD in this study
[2] <5MGD

Figure 6. Hamlin prototype sampler with SSPM sample.

Hamlin sampler placed on foil-lined cooler for SSPM removal (left), upper deflection shield removed showing inner piece and tray with baffles (top right), bowl holding SSPM and overlying water (bottom right).

Figure 7. Fuller prototype sampler with SSPM sample.

Fuller sampler placed on foil-lined counter for SSPM removal with upper deflection shield lifted showing SSPM (left), tray with baffles slightly removed from Fuller showing SSPM (top right), and removing SSPM from Fuller sampler baffles using stainless steel spoon (bottom right).

Norton

Norton bottle traps (Figure 8) were retrieved by City of Tacoma personnel. The bottles were sealed, labeled, and stored on ice in coolers and transported to the Ecology walk-in cooler.

Figure 8. Norton bottle trap with SSPM sample.

Norton bottle trap as lifted from the stormwater pipe. Leaves were carefully removed and the bottle was capped.

Bottom sediments

The Quality Assurance (QA) Project Plan for this study called for bottom sediments (from catch basins, if available) to be compared to the three in-line samplers and centrifuge sediments; but the authors also anticipated that bottom sediments would be scarce (Osterberg and Lubliner, 2011). During reconnaissance with City of Tacoma staff, we learned there would be no locations suitable for bottom sediment grabs so we installed an extra set of "Full Length" Norton bottle traps to be left in place at each Tacoma site for the full length of the study. These Norton full-length SSPM samples represented a longer timeframe for SSPM collection, like grabs from the bottom sediments of a catch basin.

Continuous-flow centrifugation

A submersible stainless steel Grundfos SP4 groundwater/well pump was lowered into the same manhole and pipe where the Hamlin, Norton, and Fuller devices were deployed (Tacoma site 237A). The pump was laid flat on the bottom of the pipe, and it pumped stormwater up the 22- feet invert, up an additional 4 feet to the top of the bank, and over an approximate 30-feet run to the centrifuge trailer. The stormwater then was carried through Teflon-lined polyethylene (1/2"ID X 5/8"OD) tubing from the pump to the centrifuges' intake port. The pump delivered more water than needed (approximately 20 liters per minute), so the rate to the centrifuges was maintained between 2 - 6 L/min using a ball-valve regulator on the intake port and an in-line excess water bleed.

The flow rate was measured on average every 15 minutes by determining the time required to fill a calibrated 1-L container with centrifuge effluent water. The efficiency of particulate retention by the centrifuges was monitored by periodically collecting water samples for total suspended solids (TSS) analysis from the centrifuges' influent and effluent tubing at nearly the same time.

After pumping and centrifugation stopped, the bowl water from each centrifuge was removed with a syringe. Solids were removed from both of the centrifuge bowls, disks, and distributors with pre-cleaned spatulas and composited into a pre-cleaned stainless steel bowl. The combined solids (from both centrifuges) were covered with aluminum foil and transported to Ecology's walk-in cooler. Figure 9 shows one centrifuge bowl with water overlaying the SSPM sample.

Figure 9. Centrifuge bowl with SSPM sample.

LISST

The LISST was calibrated prior to sampling by testing the instrument against known particle size standards. The results were acceptable and are available from the author.

The LISST was deployed concurrent with the centrifugation sampling at Tacoma site 237A. Stormwater from the centrifuge's groundwater pump was split-off into a 5-gallon bucket that was allowed to continuously overflow. The instrument was then set to operate in an automated sampling mode, with the impellor pump delivering stormwater from the bucket to the LISST reader cells at intervals varying from 5 to 15 minutes.

Figure 10 shows the LISST screen with a particle size distribution reading.

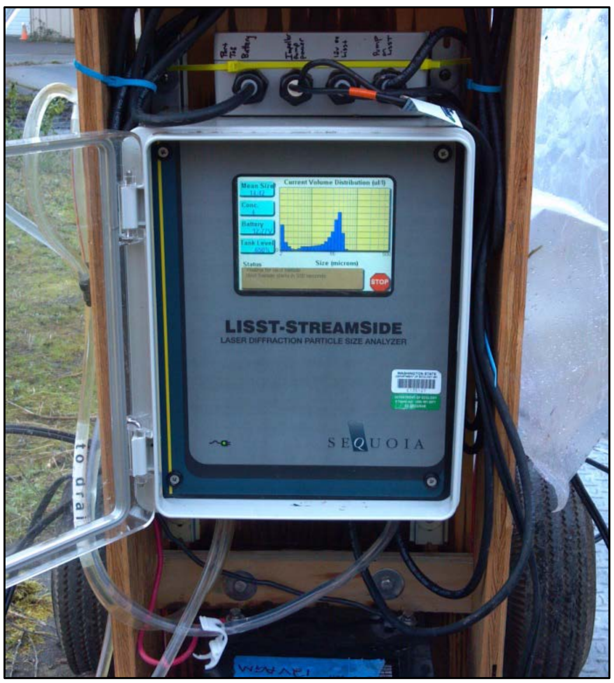

Figure 10. LISST deployed onsite.

Sample Handling and Storage

Water and sediment samples were transported to Ecology Headquarters, placed in the walk-in cooler, and allowed to settle overnight. In the morning, the bowls and bottles were carefully handled to avoid resuspending the fine sediments. The majority, but not all, of the overlying water was decanted and retained for rinses, in accordance with Ecology's SOP EAP003 (Fuller and Lowe, 2009). The Norton bottle traps had the most overlying water, in excess of 80% of the volume of the bottle, on all occasions.

The solids samples were then homogenized, in the stainless steel bowls using stainless steel spoons, to a uniform color and consistency, and subsamples were distributed to 8-oz plastic jars for centrifugation. The jars were spun in the centrifuge (VWR Scientific) at 2000 rpm for 20 minutes. If the sample required multiple centrifugation jars, contents were combined and homogenized after decanting excess water from the sample.

Solids samples were transferred to separate jars, dependent on the amount of the sample and which lab was analyzing sample. Samples were divided into jars and sent to Ecology's Manchester Environmental Laboratory (MEL) for metals, TOC, % solids, and PAHs; to TestAmerica for grain size analysis; and to Axys Analytical Services for PCB congener analysis. Due to the limited amount of solids material, a single jar was sent to MEL for all of the chemical analysis. MEL staff handled the sample distribution at the laboratory.

Decontamination

All appropriate items such as tubing, centrifuge parts, stainless steel bowls, and implements were pre-cleaned as described in the QA Project Plan (Osterberg and Lubliner, 2011). The groundwater pump is made almost entirely of stainless steel, and it was pre-cleaned by immersing and soaking for 24 hours in tap water, and then running the pump in tap water for 30 minutes. Upon deployment, the pump was run in stormwater for 5 minutes prior to use. The centrifuge-trailer plumbing-control board was cleaned with 100% methanol and de-ionized water because the controls and tubing will not tolerate the harsher chemicals used on the stainless steel implements.

Analytical Methods

Analytical methods used for this study are summarized in Table 4.

Table 4. Analytical methods used for the study of SSPM.

Parameter	Lab	Matrix	Analytical (Instrumental) Method
Total suspended solids (TSS)	MEL	Water	EPA 2540D
Grain size	TestAmerica	Sediment	PSEP (1986) Sieve and pipette
% Solids (Air dried solids)	MEL	Sediment	PSEP (1986)
Total organic carbon	MEL	Sediment	EPA 2540G, PSEP (1986)
Arsenic	MEL	Sediment	EPA 200.8
Cadmium			
Chromium			
Copper			
Lead			
Zinc			
Mercury	MEL	Sediment	EPA 245.5
Total polychlorinated biphenyls (PCBs) congeners	Axys	Sediment	EPA 1668A
Polycyclic aromatic hydrocarbons (PAHs)	MEL	Sediment	EPA 8270 SIM
HCID (Hydrocarbon identification)	MEL	Sediment	EPA 8015B

The mass of SSPM collected from each device was not always adequate to conduct all planned analyses. In this case, analyses were prioritized as follows: TOC, total solids, metals, grain size, PAH, and finally PCBs. The final number of analyses for the parameters is shown in Table 5.

All sediment samples require drying prior to measuring contaminants. 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.

Table 5. Number of SSPM analyses

Sampling Period	Number of SSPM Analyses (Field Splits)							
	%solids	TOC	Metals[1]	Mercury	Grain Size	PSD (LISST)	PAH	PCB
Tacoma #1	3	3	3	0	1	1	0	0
Tacoma #2	5	5	5	2	2	3	3	2
Tacoma #3	5	5	4	4	2	4	3	2
Tacoma #4	4 (1)	4 (1)	4 (1)	4 (1)	1	1	1 (1)	0
Tacoma #5	6 (2)	6 (2)	6 (2)	5 (2)	2	4	5 (2)	3 (1)
Centrifuge	2 (1)	2 (1)	2 (1)	2 (1)	1	2	1 (1)	1
Spokane[2]	3	3	3	3	2	2	2	2
Total Number of Analyses (field duplicates)	28 (4)	28 (4)	27 (4)	20 (4)	11	17 (0)	15 (4)	10 (1)
QAPP Number of Analyses[3]	19	17	18	13	14	17	18	12

[1] Metals analysis includes arsenic, cadmium, chromium, copper, lead, zinc.
[2] Spokane samples totaled for all three sampling intervals.
[3] The number of samples the QA Project Plan anticipated.

Deviations from the QA Project Plan

Minor deviations from the QA Project Plan were made in the experimental design, sampling methods, and analysis procedures. These deviations should not affect the quality of the data or the ability of the project to meet its objectives.

The deviations included:

- The number of storm intervals sampled was greater than planned for in the QA Project Plan. This was due to losing the Hamlin sampler on several occasions.
- SSPM sampling using the centrifuge trailer occurred on two occasions instead of one. This was due to a cessation of rain, low stormwater flows, and what was perceived as a poor SSPM mass on the first centrifugation sampling event.
- The total number of samples analyzed for the various parameters differed due to the number of storms sampled and the limited sample mass from some of the devices.

- Due to the lack of downstream catch basins, manholes, or quiescent areas, bottom sediments as described in the QA Project Plan were not collected but were replaced with a full study length Norton bottle.
- Fewer QA samples were taken due to the limited amount of solids material collected.
- SSPM with overlying water was centrifuged (to remove water) in HDPE plastic 8-oz jars instead of beakers, as recommended by SOP EAP003 (Fuller and Lowe, 2009).
- Characteristics of SSPM collected during February by each sampling device were measured using the LISST instrument as another line of evidence for true in-situ, particle-size distribution of SSPM, but results were subsequently lost.

Data Quality

This section describes how data quality was evaluated and summarizes results of the data quality review.

Representativeness

Characteristics of SSPM samples collected from each of the three sampler types were compared to each other and to material collected by the centrifuge. The sediment captured by each sampler is a field approximation of the SSPM. The representativeness of the SSPM devices to the actual stormwater particulates is evaluated by comparing the results to the centrifuge results, which are assumed to most accurately represent "true" SSPM characteristics. The City of Tacoma has employed the Norton bottle trap at site FD3 for 9- to 12- month deployments. Data are compared in the Results section of this report. To our knowledge, no prior sampling has been conducted at the manhole for this study's site 237A location; however, bottle traps have been deployed near the outfall for 237A for contaminant source tracing.

During the first sampling event (Timeframe #1), two of the Hamlin samplers were lost, and approximately 1/3 to 1/2 of the SSPM sample from the Fuller sampler was lost. Otherwise the samplers are believed to have performed as designed.

Positive implications for representativeness of each sampling device are as follows:

- SSPM characteristics (mass, particle sizes, TOC) and chemistry changed during every storm and among locations. This suggests that the devices were capable of capturing the physical variability present in the SSPM from storm to storm and location to location.
- The opacity and volume of stormwater running in the pipe were observed to both increase and decrease while sampling using the centrifuge. This demonstrates that the quality of the stormwater changed due to stormwater runoff. Baseflow was observed to be low flow and clear. The high flows sampled on February 17 were tea-colored and had obvious particulates in the water column.
- The LISST data indicate that stormwater particulates were generally <100 um, and centrifuge SSPM particle size distribution also showed a large fraction of small silt and clay particles.
- Centrifuge SSPM as "true SSPM"

- The groundwater pump used to bring stormwater from the bottom of the manhole has a screen that excludes pebbles larger than approximately 0.16" (4 mm). Although gravels (or larger particles) are certainly suspended by some flows in these particular pipes, this size exclusion is not a concern for this study.
  - Although all samplers were stationary, the range of grain sizes in all of the samples indicates the spectrum of SSPM was present and represented in the samples to the extent each sampler could capture them.
- Previous City of Tacoma SSPM data (Norton bottle) from both drainage systems were compared to results of this study, and the range of values and summary statistics are comparable.

Negative implications for representativeness are as follows:

- Two of the three devices (Fuller and Hamlin) continuously sampled the baseflow and, therefore, do not represent only stormwater suspended material. Baseflow estimations of SSPM were not quantified. The baseflow, if presumed to be cleaner stormwater, may have had a cleansing effect on the captured SSPM in the Fuller and Hamlin devices.
- There was a chance the deployment layout could have produced small biases in the particulate sizes or chemical concentrations. The devices were separated by approximately 10 feet but were only partially staggered in the flow line (see cover photo). The Hamlin sampler was located most upstream, with the Norton traps next, and the Fuller sampler most downstream. Evidence for the bias may be that the Hamlin sampler collected more fines than the Fuller. Evidence for no bias in SSPM material due to the layout of the samplers comes from two key results. First, the Fuller sampler SSPM mass outweighed the Hamlin sampler SSPM mass for two of the three occasions. Second, placement of the Nortons behind the Hamlin had no apparent effect on the fines and chemistry concentrations, as the Nortons generally had a better match to the SSPM of the centrifuge. Deployment places these traps above baseflow; therefore, any fine particulates or contaminants from baseflow were not sampled by these devices.
- Centrifuge SSPM as "true" SSPM:
  - Because the centrifuge was deployed for only two storm events while samplers were deployed for two to four weeks, the comparison of the results is subjective. There is no reason to believe the centrifuge captured two abnormal storm events; however, there is little evidence to indicate otherwise.
  - Particles larger than very fine gravel (3 mm) cannot pass through the flow regulators of the centrifuge control board.
  - Because only two storm events were sampled, the assumption is that these represent true SSPM characteristics over the entire 2011-12 study.
- The Fuller sampler was found to under-represent the finer fractions of SSPM.

Comparability

Sampling protocols and sample acceptance guidelines were consistent with ones used previously (Ecology, 2008; Gries and Sloan, 2009).

Methods and SOPs for laboratory analysis were the same as those used throughout the Pacific Northwest region for water and sediment quality studies (APHA, 2005; Ecology, 2008, 2009; MEL, 2008; PSEP, 1986).

Acceptability

Ecology staff reviewed all field measurements and laboratory analytical results for exceedances of holding times and deviations from required protocols. Quality Control sample results were compared to measurement quality objectives listed in the QA Project Plan (Osterberg and Lubliner, 2011). Substantive issues with field measurements, SSPM sampling, or laboratory analyses have not been identified, with two exceptions: (1) missing flow measurements, and (2) the use of HDPE jars for centrifuging every sample to remove overlying water. Captured flow records are discussed below.

Flow measurements

Flow measurements are secondary data from the City of Tacoma which owns and operates the meters for the sampled drainages. Flow data for both Tacoma sites are tidally influenced, so the data record included runoff and tidal flows, which were sometimes negative. The flow record at site FD3 had six days of missing data and six days of negative records. The City believes the flow meter malfunctioned due to an impact or battery failure. The records were reviewed, and negative results were removed. Overall the flow data ranges and total flows are considered estimates and are believed to be biased low.

Chemistry data

Holding times, calibrations, method blanks, laboratory control samples for general chemistry, metals, and organics data were reviewed by the project manager and deemed acceptable for use in this study.

At the request of the project manager, MEL performed a hydrocarbon identification analysis on sample 1111066-01 due to odorous smell. The sample was found to contain large amounts of weathered #2 diesel or #2 fuel oil and either lube oil or heavy fuel oil. Unfortunately, MEL, unbeknownst to the lab analyst, chose this sample to use for matrix spike and matrix spike duplicate (MS/MSD) analysis for most of the copper, lead, and zinc samples. As a result all of the lead, zinc, and most of the copper MS/MSDs failed the quality control limits, due to interfering matrix or concentrations above the spike amount. Results were qualified as “J” estimates based on the laboratory QA review or the project manager’s decision.

PAH results were reviewed by MEL staff and the project manager. PCBs results were reviewed by Axys (the consulting lab), MEL staff, and the project manager. All organics results were within measurement quality objective established in the QA Project Plan (Osterberg and Lubliner, 2011). PAH and PCB results as presented are acceptable for use without further qualification.

Qualified data

Analyte concentrations in blanks were not subtracted from sample results. A concentration of one-half the detection limit was assumed for undetected compounds. A summary of codes used to qualify the analytical data in this report is shown in Table 6.
Due to loss of sample, data for the Fuller device for the Tacoma Timeframe #1 were qualified by the author as "J" with the understanding that the values are likely biased low.

All chemistry data are available in Ecology's Environmental Information Management database available on the Internet at www.ecy.wa.gov/eim. Search the User Study ID, DOST0001.

Table 6. Qualifier flags.

Code	Description
D	The sample was diluted. Reported value is dilution corrected.
U	The analyte was not detected at or above the reported result
J	The analyte was positively identified. The associated numerical result is an estimate.
UJ	The analyte was not detected at or above the reported estimated result. The associated numerical value is an estimate of the quantitation limit of the analyte in this sample.
R	The data are unusable for all purposes.
N	There is evidence the analyte is present in the sample.
NJ	There is evidence that the analyte is present. The associated numerical result is an estimate.

Data Usability

The flow data, although qualified as estimates, are considered useable for the purposes of demonstrating flow ranges that the SSPM devices must sustain. It is not a significant issue that the flow measured at the SSPM devices is likely over-represented by the flow measured at the outfalls. In general, the flow data for this study are used to illustrate the conditions that the different devices are capable of sustaining and performing under. The deployed devices must be able to capture SSPM under all flow conditions. Flow and rainfall data from Tacoma are considered usable for this study.

All analytical data, including the Fuller sampler data from Tacoma Timeframe #1, are considered usable for the purposes of this study.

Results and Discussion

Field Measurements

Rainfall

Values recorded by an ISCO rain gage owned and operated by the City of Tacoma ranged from 0.98 to 3.82 inches per event. The rain gage located at the City of Tacoma landfill is less than two miles from the two monitoring sites. The gage is regularly maintained and was functioning properly.

Flows

The City of Tacoma maintains an extensive continuous flow monitoring program, and the pipelines monitored included those used for this study. Both flow metering locations are tidally influenced, and flow data can be negative. Range of flow rates and total flow volumes disregard the negative data and are considered estimates. Flow monitoring equipment experienced some malfunctions during the study. Data are missing for drainage pipe FD3 for a period of six days, likely due to a battery failure, so FD3 estimates are likely under-estimated. Flow data for the storm line 237A are considered over-estimates, due to the gage being located much farther downstream of the field site with additional inputs being added.

Overall, the stormwater flow rates were quite responsive to the rainfall amounts. This was expected in the highly urban environment of Tacoma, particularly for site FD3, which drains downtown. The other Tacoma site, 237A, is also highly urbanized, although the much larger drainage area required approximately 15 minutes more time of travel for stormwater flow response. Deployment dates, durations, and flow data are presented in Tables 7 and 8.

Table 7. Measured flows from Tacoma outfall OF230, downstream of field site FD3.

Tacoma Sampling Period	Dates Deployed	Deployment Duration	Rainfall (in)[A]	Range of Flow Rates (MGD)[A]	Total Flow Volume (MG)[B]
Tacoma #1	10/6/11 - 10/17/11	11 days	0.98	<1 to 31.09 J	11.6215 J
Tacoma #2	10/19/11 - 11/8/11	20 days	1.68	<1 to 19.71 J	18.694 J
Tacoma #3	11/8/11 - 11/30/11	22 days	3.82	<1 to 37.82 J	46.6274 J
Tacoma #4	12/1/11 - 1/6/12[BC]	36 days	3.06	<1 to 29.33[BC] J	20.3603[BC] J

MGD: Million gallons per day
MG: Million gallons
[A] Rainfall measured by the City of Tacoma from within the watershed.
[B] Missing data for 11/28/11 through 12/7/2011. The flow meter is tidally influenced. The SSPM devices were located upstream of the flow meter and did not have any tidal influences. Data are estimates.
[C] Flow data not available for 12/1/11 through 12/7/11. Also, the flow meter malfunctioned on 12/29/11 and started reading in the negative. Suspect large woody debris hit the sensor. Total flow is reported only up until 12/29/11. Data are estimates.

Table 8. Measured flows from Tacoma outfall 237A, downstream of field site 237A.

Tacoma Sampling Period	Dates Deployed	Deployment Duration	Rainfall (in)[A]	Range of Flow Rates (MGD)[B]	Total Flow Volume (MG)[B]
Tacoma #1	10/6/11 - 10/17/11	11 days	0.98	<1 to 46.61 J	34.87 J
Tacoma #2	10/19/11 - 11/8/11	20 days	1.69	<1 to 31.35 J	66.6 J
Tacoma #3	11/8/11 - 11/30/11	22 days	3.82	<1 to 61.01 J	115.7 J
Tacoma #4	12/1/11 - 1/6/12	36 days	3.06	<1 to 38.01 J	123.3 J
Tacoma #5	2/03/12 - 02/24/12	20 days	1.91	<1 to 24.58 J	87.2 J

MG: Million gallons
MGD: Million gallons per day
[A] Rainfall measured by the City of Tacoma from within the watershed.
[B] Flows data are estimates due to missing and negative readings. The SSPM devices were located upstream of the flow meter and did not have any tidal influences. Data are estimates.

In-situ SSPM particle size monitoring

Results of the LISST in-situ particle size measurements at Tacoma site 237A showed the following:

- The modal size of the SSPM was clay to fine sands (5-50 um diameter particles).
  - February 10 storm event. The particle median diameter hovered around 7 um.
  - February 17 storm event. The particle median diameter was around 35 um.
- The concentration and median particle size of SSPM increased with increased rainfall intensity (higher flows and higher rainfall) with some lag time due to the size of the drainage area.

Figure 11 shows the LISST data visually for the February 17 storm event.

Centrifuge operation

Centrifugation of stormwater from the 237A pipe occurred on two occasions, February 10 and 17, for 290 and 255 minutes, respectively. Total daily rainfall for February 10 was 0.02 inches, mainly in the form of morning drizzle; and was 0.41 inches on February 17, in the form of light drizzle with strong sustained downpours in the afternoon.

Centrifuge intake “sampling” flow rate was started slowly for several hours during the February 10 sampling, then increased to 6 liters per minute to increase the sample size. On February 17, the flow rate was maintained around 6 liters per minute.

Table 9 lists the centrifuge sampling times, rates, and volumes of water pumped through the centrifuge.

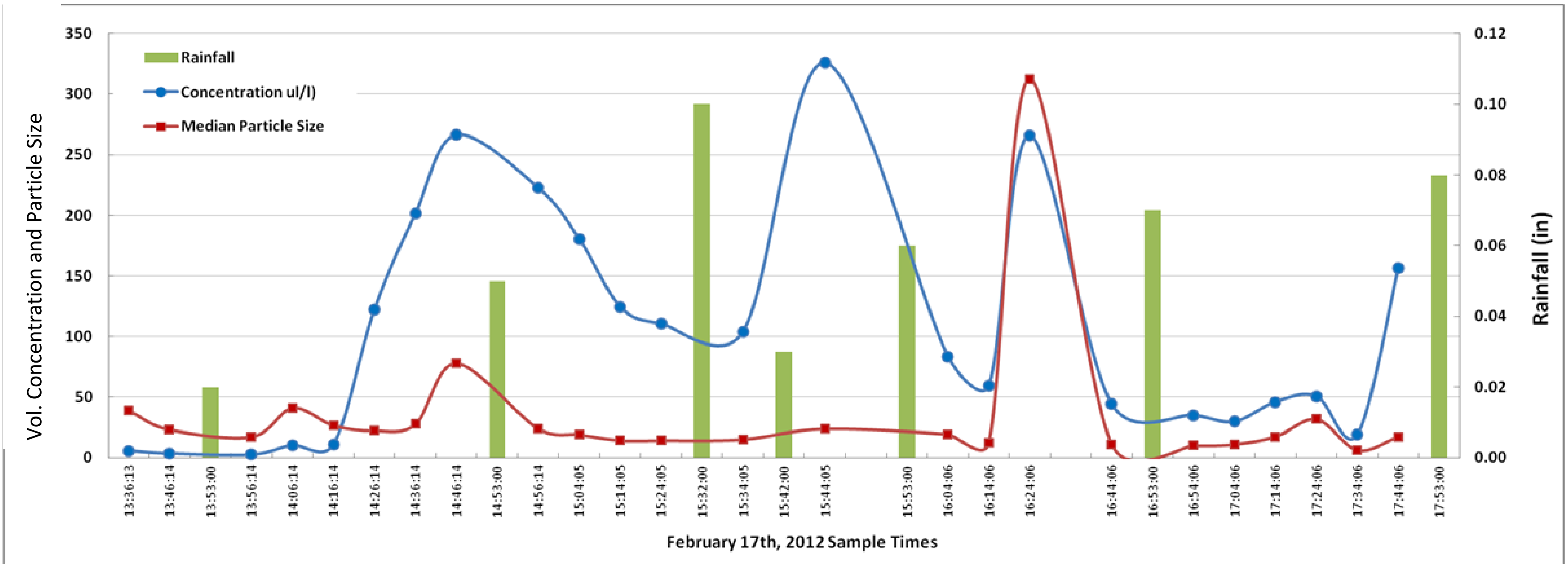

Figure 11. LISST results for February 17 storm event.

Volumetric concentrations of particles measured by the LISST (ul/L) were converted to mass-based concentration estimates (mg/L) by assuming a density of 2.6 g/cm^3 (for granitic material).

Table 9. Centrifuge sampled times, rated, and volumes of stormwater.

Date:	2/10/2012	2/17/2012
Time Sampled (min)	290	255
Flow Rates Sampled (L/min)	2 – 6.5	3 – 6
Total Volume Sampled (L)	1218	1355
Mass (g) wet weight	69	315
Mass (g) dry weight	24	137

Efficiency of SSPM captured by the centrifuge was monitored by periodic sampling TSS from the influent line and the post-centrifuge effluent (Table 10). Four paired samplings were taken throughout both days. The centrifuge efficiency was very high, with the exception of one sample that may have been field contaminated, considering the other results. Even so, the average efficiency was 88%, indicating the centrifuge captured a high degree of SSPM in the stormwater that was pumped to the centrifuge. A previous study with the centrifuge found a consistently high solids retention (~95%) (Gries and Sloan, 2009).

Table 10. Centrifuge total suspended solids (TSS) analysis.

Sample	Sample Type	Collection Time	TSS (mg/L)	Efficiency
10-Feb				
1202027-01	I	12:00:00	15	93%
1202027-02	E	12:00:00	1	
1202027-03	I	14:00:00	12	92%
1202027-04	E	14:00:00	1	
1202027-05	I	15:40:00	8	50%
1202027-06	E	15:40:00	4	
1202027-07	I	16:20:00	6	83%
1202027-08	E	16:20:00	1	
17-Feb				
1202035-01	I	14:00:00	220	100%
1202035-02	E	14:00:00	1	
1202035-03	I	16:50:00	76	99%
1202035-04	E	16:50:00	1	
1202035-05	I	17:30:00	351	99%
1202035-06	E	17:30:00	2	

I: Centrifuge Influent
E: Centrifuge Effluent

Results

SSPM physical characteristics

The Hamlin, Norton, and Fuller in-line samplers all successfully collected SSPM material from the stormwater pipelines. The rate of SSPM accumulation was calculated as the total dry weight SSPM collected over the number of days deployed.

Table 11 shows the results for mass, % solids, % TOC, and % fines (based on the grain size analysis) of each SSPM sample. Appendix B also contains a summary of laboratory results.

Notable results are summarized below:

- The Hamlin sampler collected SSPM at three locations with distinct physical characteristics from each location. Variations in the mass captured and the physical characteristics of the SSPM samples are presumed to reflect inter-basin differences in SSPM loading and drainage area land uses.
- SSPM is made up of fine particles. The grain size of the centrifuge SSPM was dominated by fines (~70%), and the LISST measurements showed in-situ SSPM was primarily in the range of 2-100 um in diameter.
- The methods comparison study, at Tacoma site 237A, found the highest to lowest sample dry mass was: Fuller, Hamlin, centrifuge, and Norton. On average, the Norton traps captured only 5-8% of the dry mass captured by the Hamlin or Fuller samplers.
- Sampling devices that allowed larger grained material to be trapped yielded the largest masses, which tended to have the lowest % fines and % TOC.
    - The highest to lowest % TOC was: centrifuge, Hamlin, Norton, and Fuller.
    - The highest to lowest % fines was: centrifuge, Norton, Hamlin, and Fuller.
- As expected, the centrifuge sediments had the highest % TOC and % fines. This is due to the centrifugal force pulling smaller particles out of the stormwater.
- With the exception of the Fuller sampler, fines and sands made up the largest fractions of the three in-line SSPM samplers. The Fuller sampler allowed larger material (up to ½ inch) to be captured, whereas the Hamlin sampler excluded material ¼ inch or larger.

Table 11. Physical characteristics of SSPM captured by each sampler and location.

Sampler and Site	SSPM Sampling Timeframe (TF)	Dates	Sample IDs	Days Deployed	Dry Weight (g)	Mass Acc. Rate (g/day)	% Solids	% TOC	% Fines (<0.062 um)
Norton at FD3	Tacoma TF 1	Oct 6 to 17	1110056-02	11	24	2.2	33.3	13.3	--
	Tacoma TF 2	Oct 19 to Nov 8	1111035-04	20	4	0.2	25.5	11.8	--
	Tacoma TF 3	Nov 8 to 30	1111066-04	22	14	0.6	31.8	15.2	--
	Tacoma TF 4	Nov 31 to Jan 6	1201022-01	37	3	0.1	18.5	4.13	--
	Full Length Deployment	Oct 6 to Jan 6	1201022-02	93	17	0.2	30.1	11.3	--
Hamlin at FD3	Tacoma TF 2	Oct 19 to Nov 8	1111035-05	20	497	24.9	74.6	1.54	--
	Tacoma TF 3	Nov 8 to 30	1111066-05	22	1072	48.7	81.7	0.75	--
Norton at 237A	Tacoma TF 1	Oct 6 to 17	1110056-03	11	28	2.6	41.3	10	--
	Tacoma TF 2	Oct 19 to Nov 8	1111035-03	20	26	1.3	54.9	6.36	--
	Tacoma TF 3	Nov 8 to 30	1111066-03	22	19	0.9	72.2	2.07	--
	Tacoma TF 4	Nov 31 to Jan 6	1201022-03	37	22	0.6	64	1.93	--
	Tacoma TF 5	Feb 3 to 24	1202059-01	21	17	0.8	72.6	0.83	--
	Full Length Deployment	Oct 6 to Feb 24	1202059-02	142	71	0.5	45.5	12.3	19
Hamlin at 237A	Tacoma TF 2	Oct 19 to Nov 8	1111035-01	20	159	7.9	53.4	6.5	11
	Tacoma TF 3	Nov 8 to 30	1111066-01	22	500	22.7	61	5.4	7.9
	Tacoma TF 4	Nov 31 to Jan 6	1201022-04	37	230	6.2	52.9 J	11.1 J	--
	Tacoma TF 5	Feb 3 to 24	1202059-03(A)	21	207	9.9	41.3	14.7	9.2
			1202059-05(A)	--	--	--	41.6	8.44	--
Fuller at 237A	Tacoma TF 1	Oct 6 to 17	1110056-01	11	382 J	34.7 J	87.8 J	0.49 J	--
	Tacoma TF 2	Oct 19 to Nov 8	1111035-02	20	631	31.6	89.9	0.4	0.1
	Tacoma TF 3	Nov 8 to 30	1111066-02	22	413	18.8	60.9	4.4	5.3
	Tacoma TF 5	Feb 3 to 24	1202059-04(B)	21	384	18.3	76.6	0.95	1.6
			1202059-06(B)	--	--	--	76.8	0.66	--
Centrifuge at 237A	Tacoma TF 5	Feb 10	1202027-09	5hrs	24	72	34.1	18	--
	Tacoma TF 5	Feb 17	1202035-07	8hrs	137	411	43.5	19.9	69
Hamlin at UnionLPT	Spokane TF 1	Nov 22 to 28	1111066-06	6	163	27.2	58.1	10.8	38
	Spokane TF 2	Jan 27 to 31	1202023-01	4	207	51.8	56.9	8.72	42
	Spokane TF 3	Feb 28 to Mar 2	1203042-01	3	108	36	61.9	9.36	--

Acc.: Accumulation
-- Not enough material available to process sample for this parameter.
(A) Samples 1202059-03 and 1202059-05 are field splits.
(B) Samples 1202059-04 and 1202059-06 are field splits.

Mass accumulation rate

Dry mass accumulation rate is estimated by dividing the dry weight by the number of days deployed. This gives a relative means of comparing the SSPM collection capabilities of the various sampling devices. Figure 12 illustrates the rate of SSPM mass accumulation, averaged across all storm events by sampling technique.

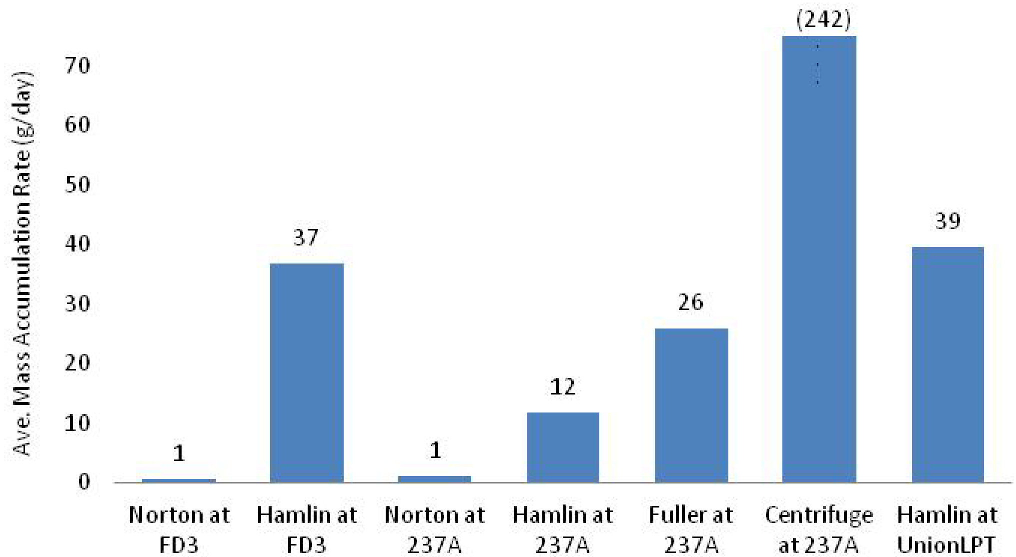

Figure 12. Average dry mass accumulation rate of SSPM per sampling device and site.

Both the Fuller and Hamlin samplers out-performed the Norton bottle trap at capturing a larger sample size for a given timeframe. Focusing only on site 237A, where the devices were deployed concurrently for the comparison study, the continuous centrifugation of stormwater produced the fastest rate of mass accumulation. In decreasing order, the Fuller sampler captured the next largest mass for each storm event, followed by the Hamlin and Norton. The slow rate of capture of the commonly used Norton bottle trap is one of the main reasons a new SSPM sampling device for contaminant tracing is needed.

Grain size

Figure 13 shows grain size properties of the SSPM from each sampler. Grain size was measured using PSEP sieve and pipette protocols.

Centrifuge

The centrifuge SSPM was found to be very fine: 69% silt, 30% sand and only 0.5% gravel. Centrifuge efficiency was 92-100% for influent TSS values larger than 10 mg/L. These results concur with previous studies that found the centrifuge removes influent SSPM (TSS) with 92-99% efficiency at the delivery rate of 3.0 liters per minute or 92% efficiency under a flow rate of 3.5 L/min (Gries and Sloan, 2009). In other words, SSPM sampled from 1355 liters of stormwater at site 237A on February 17 during a moderately sized storm event (0.41 inches) was predominantly silt and, to a lesser extent, sand.

In-line samplers

Figures 13 and 14 show the grain size make up of the SSPM collected by the three in-line samplers compared to the centrifuge SSPM. The fines (clay and silt) dominate the SSPM collected by the centrifuge, whereas for the other devices, the sand fractions are larger. The notable exception is the Fuller device's SSPM is comprised of 50% pebbles. This is due to the half-inch grating on the top of the Fuller sampler that allows these larger pebbles to be captured.

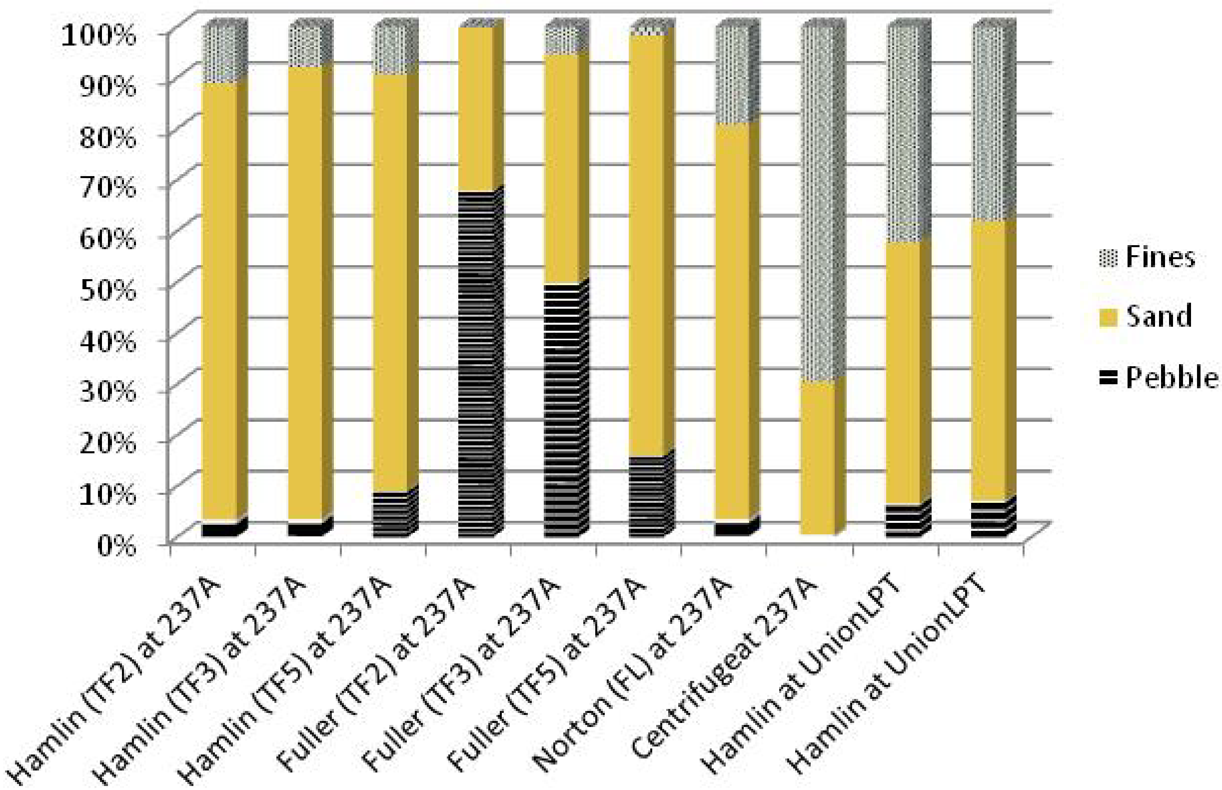

Figure 13. Mass partitioning of fines (clays and silts), sands, and pebbles (Wentworth scale) in SSPM from sites 237A and UnionLPT.

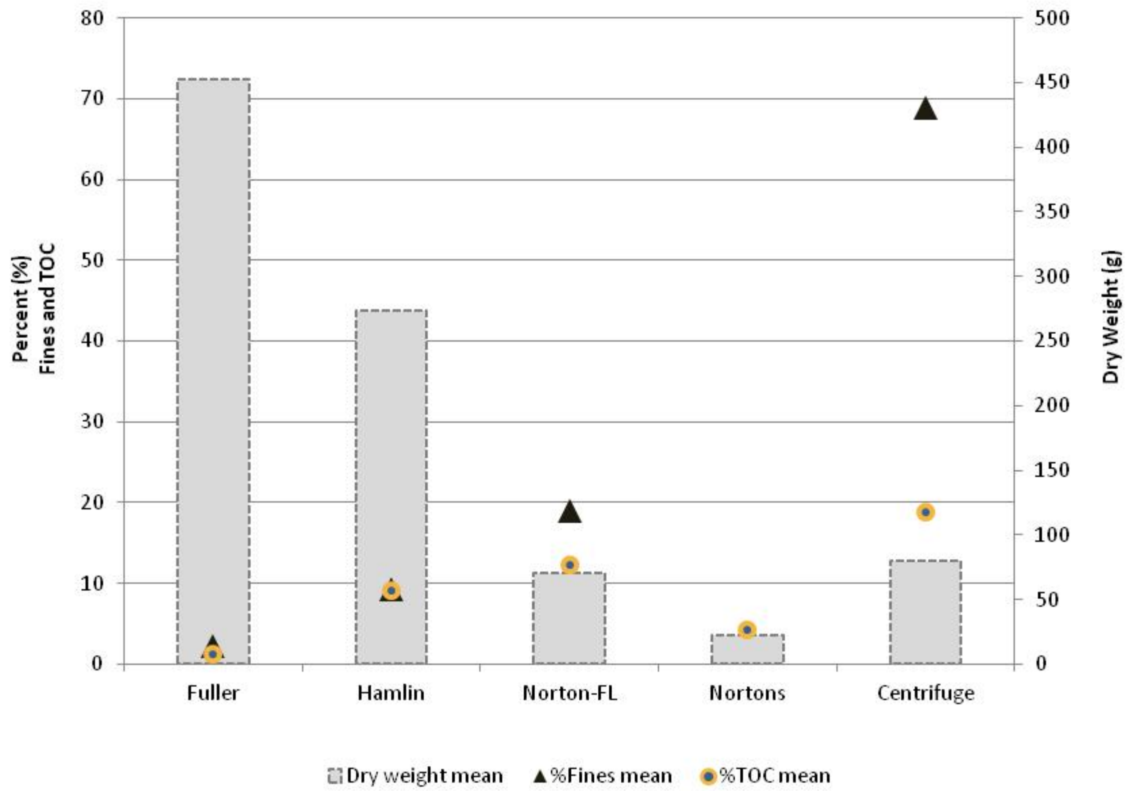

Figure 14. Comparison of average dry weight, % fines, and % total organic carbon (TOC) for SSPM samples from Tacoma site 237A.

Norton-FL and Centrifuge have only one sample and are, therefore, represented by only the single data point (see Table 11).

SSPM chemistry

Total Organic Carbon

Sources of carbon in SSPM include degrading plant materials and manmade sources in both particulate and dissolved form. As shown in Table 11 and Figure 14 above, the centrifuge SSPM had the largest % TOC, followed by the Norton, Hamlin, and Fuller. These TOC values are larger than typical marine embayment TOCs, but the stormwater environment is likely to have higher litter fall debris. Higher TOC in stormwater could be explained by leaves, windfall, and other carbon sources that are ground up by natural detritus processes, traffic, and abrasion along the lengths of the concrete stormwater pipes in these large cities (Tacoma and Spokane).

Contaminants

Contaminant chemistry analyses were performed on the SSPM collected from the samplers as sample mass allowed. Parameters with a strong affinity for particulates were selected, including (in priority order):

- Metals
  - Arsenic (As)
  - Cadmium (Cd)
  - Chromium (Cr)
  - Copper (Cu)
  - Lead (Pb)
  - Zinc (Zn)
  - Mercury (Hg)
- Organic compounds
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Polychlorinated biphenyls (PCB congeners)

A large fraction of the metals and nonpolar organics in stormwater discharges is adsorbed to solids, especially to small particulates whose high surface-to-volume ratios provide reactive sites for partitioning (e.g., Sansalone and Buchberger, 1997; Krein and Schorer, 2000; Shinya et al., 2000; Furumai et al., 2002; Stenstrom and Kayhanian, 2005). These contaminants can cause receiving water quality degradation and toxicity and also can pose significant health risks.[3]

Metals

Metals concentrations tended to follow the same pattern found with % fines. The results are presented in Figure 15 and Table 12 and are summarized below:

- For prototype testing of the Hamlin sampler, SSPM samples had a range of values for the metals at each of three sites, reflecting the variable chemistry of stormwater sediments in different settings.
- In the comparison study at Tacoma site 237A, the highest concentrations of the seven metals were captured by the centrifuge. Concentrations for the three in-line samplers were as follows:
  - Fuller metals concentrations were the lowest of all the sampling devices.
  - Norton and Hamlin metals concentrations most closely matched those in the centrifuge SSPM.
- The methods comparison study showed that the average metals concentrations for the individual timeframe deployments for the Norton and Hamlin samplers were equal to the full length deployment of the Norton sampler.

[3] Cadmium, lead, mercury, PAHs, and PCBs are persistent, bioaccumulative toxics (PBTs) that are a hazard for aquatic life and human health (www.ecy.wa.gov/programs/swfa/pbt). The other metals analyzed also have toxic properties and can bioaccumulate but are not classed as PBTs.

Because the largest concentrations of metals and organics were from the centrifuge SSPM, we believe these contaminants were associated with the fines. If the centrifuge represents the “true” chemistry of the SSPM, then all three in-line SSPM devices under-estimate metals and organics concentrations in SSPM (i.e., biased low).

Results in Table 12 were compared to freshwater sediment quality values to point out the utility of the devices to capture SSPM for contaminant source tracing. The freshwater sediment screening level~~s~~ for arsenic (14) and cadmium (2.1) and the cleanup level~~s~~ for chromium (88) (mg/Kg dw) (Michelsen, 2011) were exceeded only by the centrifuge SSPM at field site 237A.

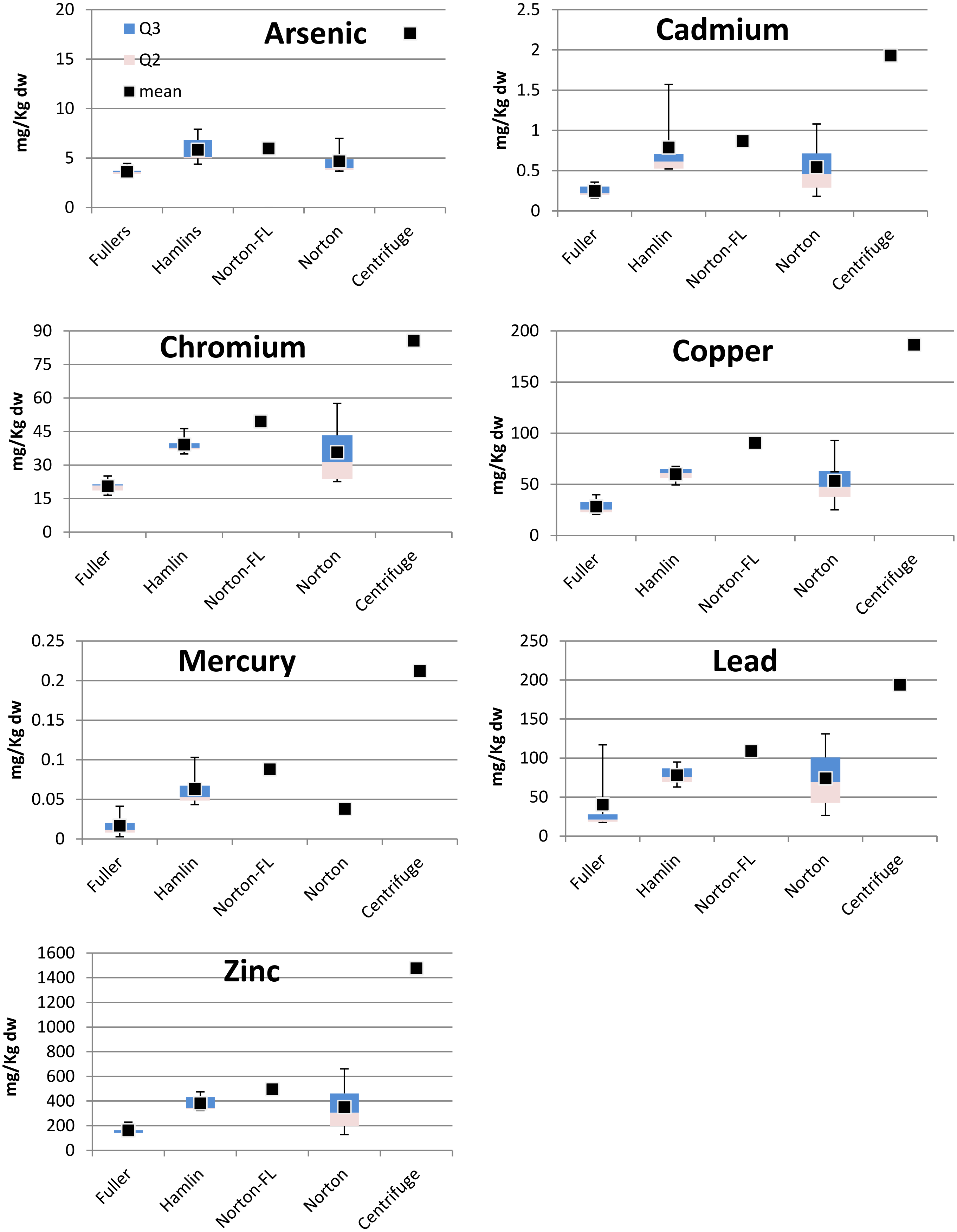

Figure 15. Box plot and quartile comparison of metals values by sampling device at Tacoma site 237A. *Norton-FL represents only one sample, and the centrifuge represents only two samples. See Table 12.*

Table 12. Metals and organics concentrations in SSPM captured by each sampler at Tacoma site 237A.

Sampler and Site	Sample IDs	Metals (mg/Kg) dw							Organics (ug/Kg) dw	
		As	Cd	Cr	Cu	Hg	Pb	Zn	PAHs	PCB[1]
Norton at 237A	1110056-03	7	1.08	58	93	--	131	661	--	--
	1111035-03	4.2	0.59	39	53	--	91	395	--	--
	1111066-03	--	--	--	--	--	--	--	--	--
	1201022-03	3.7	0.33	23	42	0.04	48	218	--	--
	1202059-01	3.8	0.18	24	25	--	26	129	--	--
	1202059-02	6	0.87	50	91	0.09	109	496	49400	402
Hamlin at 237A	1111035-01	5	1.57	46	68	--	95	475	21994	291
	1111066-01	4.4	0.53	38	49	0.04	69	335	29879	139
	1201022-04	5.1	0.71	37	65	0.1	76	431	31458	--
	1202059-03[a]	7.9	0.61	40	61	0.06	87	345	38188	245
	1202059-05[a]	6.8	0.52	35	56	0.05	63	323	52793	140
Centrifuge at 237A	1202027-09	21.4	2.26	95	228	0.28	208	2050	--	--
	1202035-07	13.8	1.6	76	145	0.15	180	902	40853	273
Fuller at 237A	1110056-01	3 J	0.3 J	17 J	21 J	--	17 J	138 J	--	--
	1111035-02	3.7	0.16	21	25	0	18	143	971	4.7
	1111066-02	3.6	0.36	25	40	0.04	117	229	11728	59.1
	1202059-04[b]	4.5	0.22	21	33	0.01	28	164	4459	45.1
	1202059-06[b]	3.4	0.2	19	23	0.01	21	139	7635	--
City of Tacoma at FD2[2] (just below 237A)	(median of 4 samples)	--	0.85	--	58	0.51	94	326	--	52[c]

1 Sum of PCB congeners.

2 City of Tacoma data collected using Norton bottle traps was provided for comparison.

a Samples 1202059-03 and 1202059-05 are field splits.

b Samples 1202059-04 and 1202059-06 are field splits.

c Sum PCB Aroclors from data provided by the City of Tacoma. PCB Aroclors (1016, 1221, 1232, 1242, 1248, 1254, and 1260) are analyzed differently than PCB congeners used by this study. Aroclors may not be directly comparable to congeners (Golding, 2010); however, a ballpark comparison shows the relative agreement to the City of Tacoma data.

Organics

Total PAHs and total PCB congeners measured as part of this study make up a list of many individual compounds. Summarized homologues and LPAH and HPAH results can be found in Appendix B; individual compound results are available from the author. Due to limited sample material from the Norton-FL and centrifuge sampling devices, only one analysis for PAH and PCB congeners was completed. Concentrations of the total PAH and PCBs at Tacoma site 237A are listed in Table 12.

A recent study in Everett, WA characterized SSPM contaminant concentrations by comparing samples from the same continuous flow centrifuge to SSPM samples from in-line filtration bags devices (SAIC, 2012). They found that the centrifuge concentrations of PCBs and PAHs were more than 5 times higher than the SSPM of the filtration bags. Likewise, the percentage of the fines (silt/clay) was also approximately 5 times higher (SAIC, 2012). This study did not find such large differences for organics concentrations in the centrifuge SSPM as compared to the three in-line devices; the ratio was more or less 1 with the exception of the Fuller device. The centrifuge, Norton, and Hamlin average concentrations were approximately 7 times higher than the overall average for both PAHs and PCBs from the Fuller SSPM (Table 12).

PAHs

PAH concentrations varied widely among the sampling devices. The release of PAHs into the environment is widespread since these compounds are ubiquitous products of incomplete combustion. Generally, PAH solubility decreases and hydrophobicity increases with an increase in molecular weight. In addition, volatility decreases with an increasing molecular weight. Environmental fate and transport studies often distinguish the high molecular weight PAH (HPAH) from the low molecular weight PAHs concentrations (LPAH). LPAHs are more soluble and volatile and are less likely to be found in older contaminated sediments. On the other hand, HPAHs are often the focus of contaminated sediment cleanups.

Figure 16 shows the sum total of the LPAH[4] and HPAH[5], dry weight (dw), concentrations for SSPM samples from site 237A. Figure 17 shows the concentrations of LPAHs and HPAHs separately. The limited data set prevented meaningful statistical analyses.

[4] LPAH: sum total of low molecular weight PAHs: naphthalene, anthracene, acenaphthylene, acenaphthene, phenanthrene, and fluorine

[5] HPAH: sum total of high molecular weight PAHs: fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

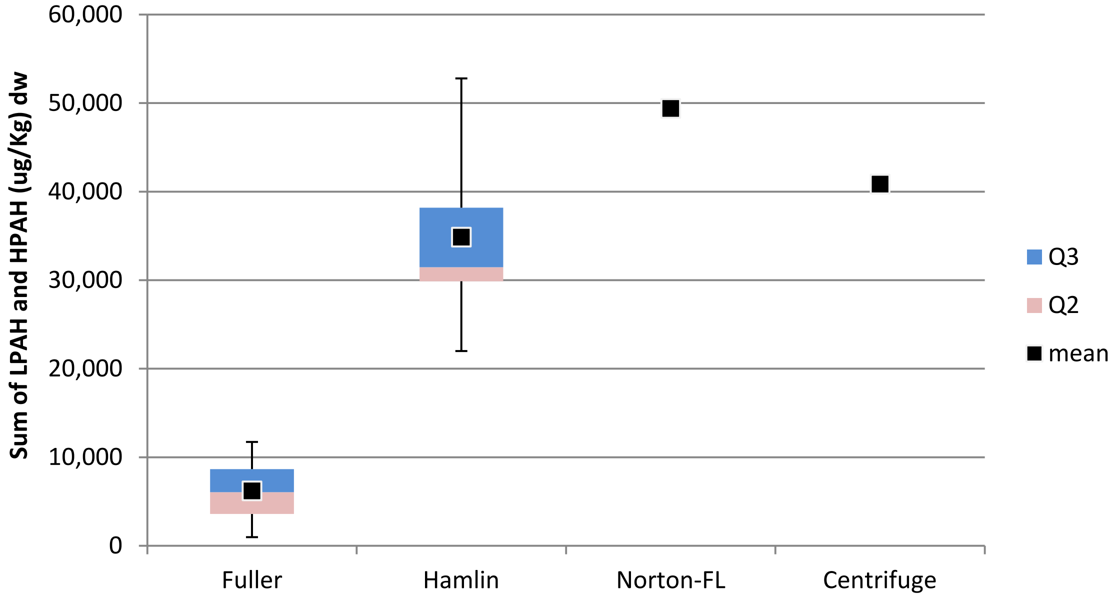

Figure 16. Total PAH concentrations by sampling device at Tacoma site 237A.

Norton-FL and centrifuge have only one sample and are, therefore, represented by only the single data point and not the quartile ranges. (See Table 12.)

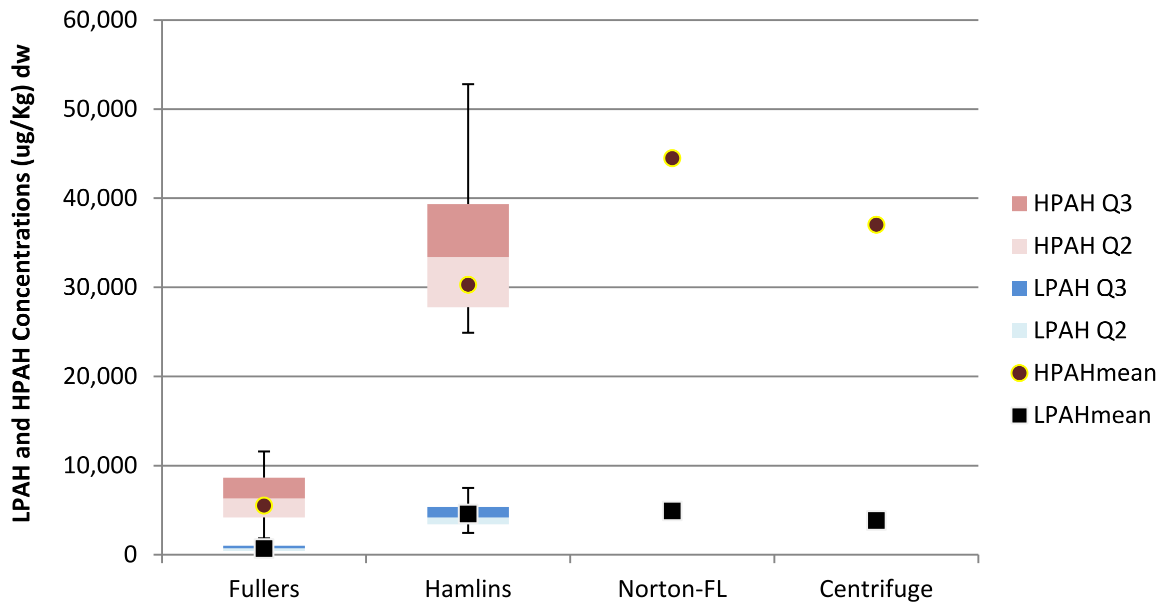

Figure 17. Concentrations of low and high molecular weight PAHs.

Norton-FL and centrifuge have only one sample and are, therefore, represented by only the single data point and not the quartile ranges. (See Table 12.)

The wide range of PAH concentrations from the Hamlin device is likely a reflection of the variation in stormwater sediment concentrations, timeframe of deployment and storm sizes. With only one sample for comparison from the Norton-FL device and centrifuge, the variability is not known for those two devices. The SSPM from the Fuller device had lower PAH concentrations as compared to the other three devices. The large variation in the sum total PAH concentrations between devices was not due to the treatment of non-detects. Non-detects made up only 11% of the data set. Substitution of one-half the detection limits for non-detects accounted for less than 1% of the total concentration increase when compared to substituting zero for the non-detects. The only exception was the Fuller 1111035-02 sample which using one-half versus zero for the non-detect concentration, accounted for 6.7% of the total concentration (data not shown).

Interestingly, the SSPM concentrations for the Norton-FL and centrifuge are within the upper quartile of the Hamlin SSPM concentrations. All three are well above the Fuller SSPM concentration and well above the freshwater sediment quality values of 17,000 ug/Kg for the Sediment Quality Standard (SQS) and 30,000 ug/Kg for the Cleanup Screening Level (CSL) (Michelsen, 2011). The marine sediment SCS and CSLs for HPAH, based on 2003 lowest apparent effects thresholds, are 31,640 and 54,800 ug/Kg, respectively (Michelsen, 2003). At least one SSPM sample from the Hamlin, Norton-FL, and centrifuge exceeded (did not meet) the HPAH marine sediment standards. Again, this project was designed to compare SSPM from different sampling devices and their utility as source tracing tools.

The Hamlin, Norton, and centrifuge SSPM were all of a finer nature than the Fuller SSPM, which contained approximately 50% pebbles as described earlier. The finest particles (clays and silts) have been referenced by the literature as highly associated with contaminant transport (SAIC, 2012; Juhasz and Naidu, 2000). The Norton and Hamlin devices, which can capture but also retain the fine sediments, have the highest associated contaminants, such as metals and hydrophobic organics.

SSPM concentrations of HPAHs are much higher than the SSPM concentrations of LPAHs. Previous sampling results from the City of Tacoma are comparable and were collected using a Norton bottle trap lower in this same pipeline. The median concentrations from four years (2008-2011) at FD3 were 2520 ug/Kg dw for LPAH and 17,745 ug/Kg dw for HPAH. Non-detects were calculated using half the detection limit. (City of Tacoma data, unpublished).

PCBs

PCBs were banned in the United States in the 1980s, due to ecological concerns, but they remain persistent in the environment. In this study, we measured PCB congeners, not PCB Aroclors. PCBs are manufactured as Aroclors but break down into individual PCB compounds called congeners, after they are used. There are 209 PCB congeners, and the sum total is presented here. Other studies have found considerable overlap in congener composition between Aroclor-equivalents (Sather et al., 2001), and attempts to estimate Aroclor-equivalent concentrations are considered to be difficult and potentially biased when several Aroclors are suspected to be present (Feddersen, 2001; Kaye, 2002; Golding, 2002). The proposed freshwater sediment SQSs or CSLs are for PCB Aroclors (110 and 2500 ug/Kg dw, respectively) (Michelsen, 2011).

Therefore, results from this study are not directly comparable to freshwater sediment standards or the City of Tacoma's results.

Figure 18 shows the quartiles for the Fuller and Hamlin SSPM results and the single data point for the Norton-FL and centrifuge SSPM.

Figure 18 also shows the percentiles and means of the total PCB congeners measured in the SSPM collected by the four sampling devices.

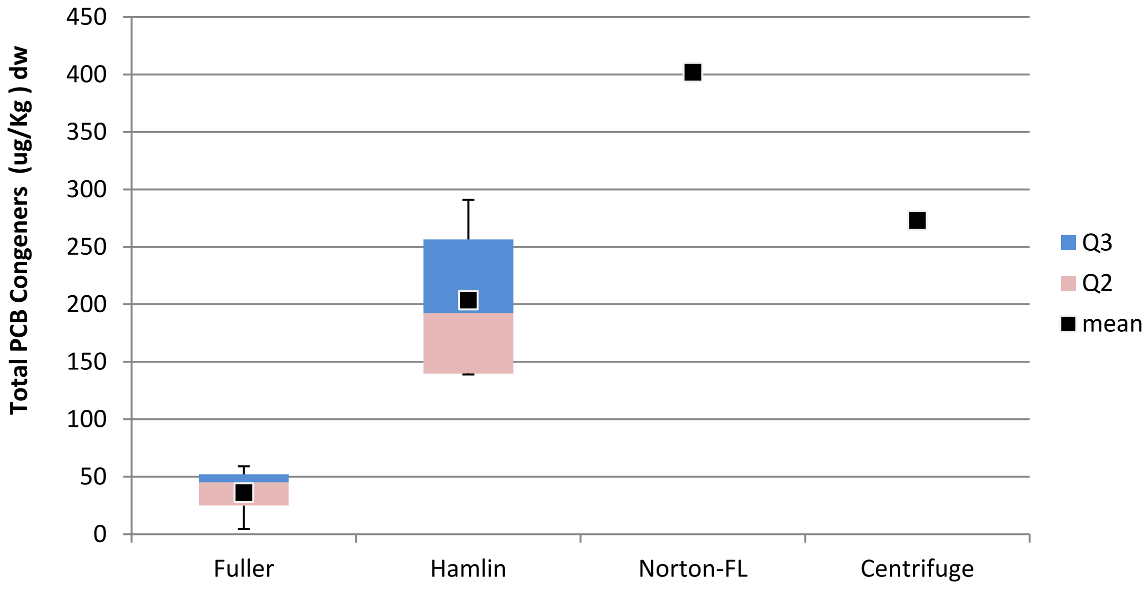

Figure 18. Concentrations of Total PCB congeners by sampling device at field site 237A.

Norton-FL and centrifuge have only one sample and are, therefore, represented by only the single data point and not the quartile ranges, see Table 12.

Like metals and PAHs, higher PCB concentrations are typically associated with fine sediments. The highest concentrations were found in the SSPM from the Norton-FL and centrifuge, whose sediments were the finest. The highest PCB concentration was found in the Norton-FL SSPM, which suggests that the long-term average PCB concentration may have been higher than the PCB concentration in the SSPM on the day that centrifugation was used.

Normalized organics

The pattern of the Fuller sampler collecting fewer fines and lower organic chemistry concentrations than the other samplers was cross-examined using a common technique of normalizing the non-polar organic concentrations to the TOC. Normalization is commonly done for organic contaminants to evaluate toxicity and compliance with SQSs. Concentrations and toxicity of nonpolar and non-ionizable organic chemicals in sediment samples are commonly correlated to organic carbon in the sediment (Michelsen, 1992).

Table 13 and Figure 19 show the organic carbon-normalized results from the four devices at site 237A.

Table 13. Concentration averages for each sampling device at Tacoma field site 237A.

Sampling Devices	%TOC	OC-Normalized[1] (ug/Kg OC)	
	Average (Range)	Norm_PAH	Norm_PCB
237A Fuller Single Deploy	1.3 (0.4-4.4)*	*	*
237A Hamlin Single Deploy	9.23 (5.4-14.7)	412,076	2,594
237A Norton-FL	12.3	401,626	3,268
237A Centrifuge	18.9 (18 -19.9)	205,291	1,372

* not deemed suitable for normalization to organic carbon (Michelsen, 1992).
1 average of the normalized results for each device.
TOC: total organic carbon.

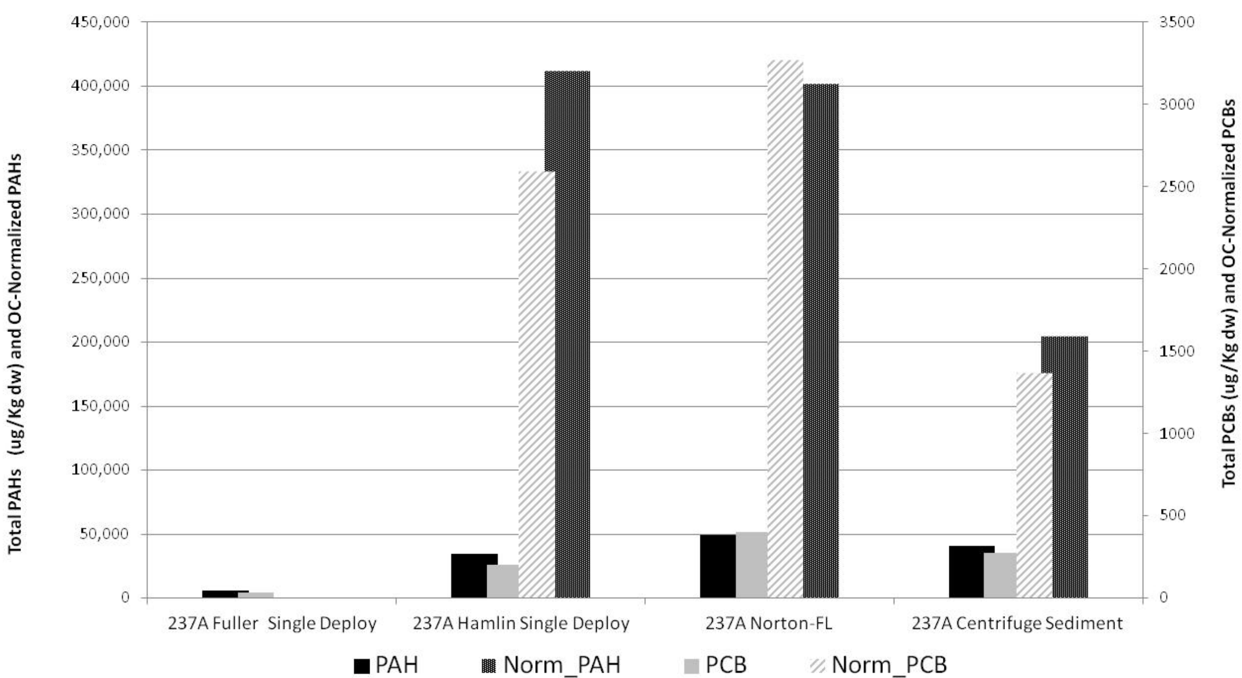

Figure 19. PAH and PCB dry-weight and organic carbon-normalized concentrations.

Normalizing data divides the dry weight concentration by the TOC value. If TOC is a number less than one, then mathematically, the larger the OC-normalized value becomes. Normalization is not typically done when TOC values are less than 5%, when OC may be derived from man-made sources, or when sampled sediments are not considered "normal" sediments (Michelsen, 1992). SSPM is generally not considered to be "normal" depositional sediment and has the potential for man-made OC sources. The Fuller SSPM normalized results are not accurate due to the TOC <5% and therefore are not shown.

The OC-normalized chemistry data compared to the dry-weight concentration data for PAHs show that the pattern or differences between the data sets change consistently for all four sampling devices. The OC-normalized PCB and PAH data are highest for the Norton-FL and Hamlin devices, likely due to the lower TOCs. In general, the question, *Does stormwater sediment TOC variability exclude it from OC-normalized procedures?*, needs more data to be answered.

TOC in the Fuller SSPM was so low it was deemed not suitable for normalizing the PAH and PCB concentrations. The OC-normalized PAHs or PCBs for the centrifuge SSPM were the lowest of the four sampling devices. This is due to the relatively high TOC values, which is probably due to the centrifugal force pulling the fine, low-density carbon particles from the water column. It is believed that the low-density and high carbon particles could be from man-made carbon sources or perhaps from leaf, twig, and small branch material that are ground to very fine particulates as they travel down the abrasive concrete pipes (Rick Fuller, personal communication 2012).

Summary

In summary, this project used a continuous-flow centrifuge and real-time particle size monitor (LISST) to sample stormwater for suspended solids and to serve as a "ground truth" SSPM sample for comparison of three passive deployed sampling devices. In-situ SSPM was found to be dominated by fines (clay/silt) and fine sands. Ecology's Norton bottle trap and the Hamlin prototype sampler were found to best match the centrifuge's SSPM sample for particle-size distribution and monitored contaminants. The Fuller SSPM was made up of larger particles (sand and gravel); this device allowed fines to wash out of the sample and, therefore, under-sampled for fines and contaminants. Table 14 provides estimates of cost effectiveness by sampler.

Table 14. Comparison of cost and time for each sampling device at Tacoma field site 237A.

Sampling Device	Norton Bottle	Hamlin	Fuller	Centrifuge
Approximate Capital Cost[1]	$100	$250	$500	$100,250[2]
Ease of Use and Cleaning	Moderate[3]	Easy - Moderate[3]	Moderate[3]	Difficult[4]
Resist Fouling[5]	Moderate-Well	Poor - Well	Well	Moderate
Labor (FTE-days) per Storm Event[6]	$1750	$1750	$1750	$1750[7]
Particle Size Distribution Range	Fines	Fines - Sands	Sands - Gravels	Fines – Fine sands
Total Organic Carbon (TOC) Range (%)	12.3 (moderate)[8]	5.4-14.7 (low to moderate)	0.4-4.4 (very low to low)	18 -19.9 (very high)
Days to Capture 50g of SSPM[9]	50	4.2	1.9	0.2

[1] The 3 passive samplers are not commercially available, so costs vary because of materials and the price of labor at the local manufacturing shop.
[2] The complete set up (trailer, generators, and two refurbished continuous-flow centrifuges) were purchased in the late 1980s for approximately $100,000 dollars. Centrifuge use included an annual maintenance to the generator, and trailer is estimated to be $250.
[3] In this study, deployment of the 3 in-line samplers in Tacoma required confined space entry, manual lowering of staff into manholes, bolting the devices to the concrete, and retrieval in-between storm events. This is deemed moderate due to the trained personnel requirement for confined spaces. In Spokane, use of the Hamlin device was simple. Cleaning of the Norton and Hamlin devices were the easiest.
[4] Deployment using the centrifuges was difficult and required timing the outing with active storm events, staff availability, and daylight hours in the winter. The groundwater pump, tubing, and centrifuges all require extensive cleaning prior to each deployment.
[5] In general, all 4 devices were susceptible to damage or blockages by garbage and leaves. The Hamlin sampler was lost early in the study. Lessons for deployment were learned, including that the prototype device, including the tongue piece, needs to be bolted down in high-energy environments. Once this was figured out, the sampler resisted fouling well. The centrifuge intake lines have very small diameters and must be routinely monitored for blockage.
[6] This is a gross estimate of labor required for set up and removal of samplers. Each day a minimum of 3 City of Tacoma staff and 2 Ecology staff were present for passive sampler deployment and retrieval. Approximately ½ day of labor for each FTE, and FTEs salaries are all calculated at $350 per day. The days while the 3 passive inline samplers were deployed are not included because no one was present. This does not include a day spent cleaning all 4 devices for each event.
[7] Each centrifuge deployment required 3 Ecology staff for 1.5 days, plus ½ day for centrifuge and trailer maintenance.
[8] TOC range shown for the Norton Bottle trap is for the "full length" timeframe.
[9] Dry mass accumulation rate from Figure 12.

Conclusions

The following conclusions are drawn from the results of this 2011-2012 study:

- The Fuller and Hamlin sampling devices retained a larger quantity of SSPM mass than the Norton bottle trap during the same deployment duration. However the Norton bottle trap and Hamlin sampler best matched the particle-size distribution and contaminant chemistry of the SSPM captured by the centrifuge.
- The Fuller device was inefficient in terms of retaining fines, capturing total organic carbon, and obtaining representative contaminant concentrations.
- The longer (3-month) deployment of the Norton bottle traps contaminant chemistry most closely matched SSPM, as captured by the centrifuge.
- The Hamlin device could successfully be used in place of existing Norton bottle traps to collect a larger mass of SSPM over the course of a shorter, approximately 2-week, timeframe that is comparable in contaminant chemistry captured by the Norton bottle traps.

Recommendations

Results of this 2011-2012 study support the following recommendations:

Stormwater Sediment Study

- The Hamlin sampler should be used when a larger mass of SSPM is desired, in a shorter period of time, for chemical analysis. The Hamlin, with slight design modifications listed below, is an affordable and easy device for SSPM contaminant tracing.
- Use of the Norton bottle trap appears to be the most representative, when compared to the centrifuge SSPM, but provides a much slower means to capture SSPM.
- The Fuller sampler should not be used in its current form to capture SSPM for contaminant analysis. The finer SSPM is under-represented; therefore, the results are biased low for contaminants and total organic carbon.

Sampling Devices

- The Hamlin device design should be modified to improve form and function for deployment:
  - Drill holes in the tongue piece to allow anchoring which will prevent tongue from lifting under larger flow rates.
  - Round or file exposed cut metal edges to prevent laceration.
  - Develop a locking mechanism to keep tray, separation pieces, and tongue in place once assembled to deploy down narrow manhole shafts.
  - Use “stop nuts” or nuts with rubber gaskets inside threaded nut to prevent shaking or wiggling free of the pipe anchors.
- The Fuller device was in the early prototype phase and would require design changes to retain the sought-after finer fractions of SSPM.
- Both the Hamlin and Fuller devices were too long to fit into the manhole without tipping one end up, which jeopardized losing some of the SSPM and overlying water sample. These devices should be made to fit through manholes without tipping.
- The Norton bottle trap fits a 1-liter bottle. A narrow bottle mouth was used in this study; however, a wide bottle mouth could potentially improve SSPM collection, although probably not significantly.
- The continuous-flow centrifuge should still be used for comparison studies or characterization monitoring for stormwater contaminants. More data to better define “true” SSPM concentrations should be gathered.

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Appendices

Appendix A. Detailed Maps of Tacoma Sampling Stations

The following basin descriptions are from the 2011 Stormwater Monitoring Report (City of Tacoma, 2011). Figures were provided by the City of Tacoma. Figure A-1 shows both drainage areas and land use.

Land use

The following page is:

Figure A-1: Land use map for downtown Tacoma (Courtesy City of Tacoma).

On the web, Figure A-1 is linked to this report as a Supplemental Document.

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Site 237A

Figure A-2: Aerial photo of sampling site 237A (Courtesy City of Tacoma).

Baseflow for outfall 237A is continuous and is derived from old creeks that were piped. Basin 237A is approximately 2,794 acres and drains to Thea Foss Waterway through the west 96-inch outfall located in the 2300 block of E. Dock Street at the head of the waterway. As shown in Figure A-3, the drainage basin generally extends in a westerly direction from the outfall. The general boundaries are South 19th Street on the north, South 40th Street on the south, Lawrence Street on the west, and Tacoma Avenue on the east. Industrial land use, nearly 13% of this basin, is mainly located in the Nalley Valley area between SR-16 and I-5. Residential land use is 60% of the basin with commercial land use at 22% and multi-family at 3%. Freeway right-of-way is a very small percentage of the basin but it may increase with 2005 to 2011 expansions and HOV lanes on State Route 16 and Interstate 5, which includes the entire State Route 16 interchange, and a portion of Interstate 5- Interstate 705 interchange.

Baseflow in outfall 237A is continuous from former creeks that were piped. The flows originate from seeps in three major areas: seeps near the railroad tracks along South Tacoma Way in Gallagher’s Gulch, a seep in Nalley Valley, and a railroad tunnel spring and seeps in a ditch along the Hood Street corridor from S 25th Street to S 23rd Street.

Baseflow for outfall 237A is approximately 2.8 cubic feet per second. In January 2011, Tacoma confirmed that the railroad tunnel spring originally thought to discharge to OF235 actually discharges to the 23rd Street lateral of Basin 237A and OF237ANew.

In 2011, the artesian well baseflow in the old 237A pipe was rerouted from 237B to 237A during construction of the Sounder Corridor (see Section A.4.1). The baseflow rate in OF237A should increase after construction of the new pipe is complete (City of Tacoma, 2011)

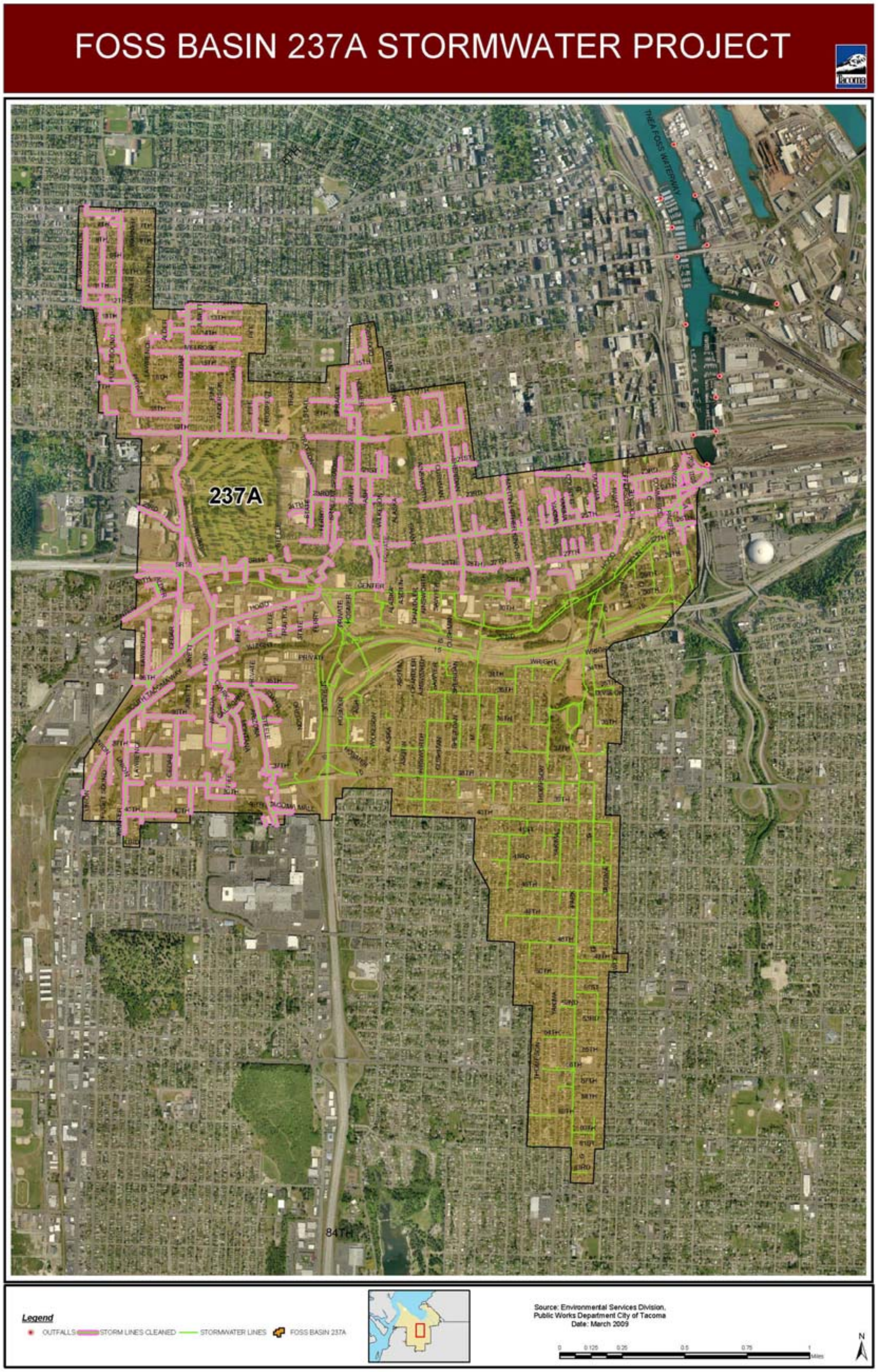

Figure A-3. Entire drainage area of site 237A (Courtesy City of Tacoma).

Site FD3 (230)

Figure A-4: Aerial photo of sampling site FD3 (Courtesy City of Tacoma).

Baseflow for outfall 230 is continuous and is derived entirely from infiltrating groundwater. Basin 230 is located on the mid-portion of the west side of Thea Foss Waterway. The basin boundaries are shown in Figure A-4. The area is approximately 513 acres and discharges to the waterway through a 60-inch outfall pipe located at S 15th Street and Dock Street on the side of Johnny's Seafood (retail). The general basin boundaries are S 8th Street to the north, S 17th Street to the south, S Ainsworth Avenue to the west, and Dock Street to the east. Most of the storm drainage is channeled to S 15th Street via a main trunk line along Market Street. Because of the steep downhill grade, overflow pipes in manholes along Market Street direct excess water to downstream trunk lines. Trunk lines along Dock Street are susceptible to saltwater intrusion from high tides.

Basin 230 is heavily developed, with roughly 58% of the land used for commercial purposes. Street right-of-ways account for over 42% of the basin. Residential development is generally confined to the western end of the basin, accounting for 30% of the total land use with multi-family at 11%.

The northern portion of the University of Washington – Tacoma (UWT) discharges to outfall230. The drainage area for UWT is bounded by Pacific Avenue, S 21st Street, Tacoma Avenue, and S 17th Street. Also included in the basin is Tacoma Light Rail – LINK, Tacoma Convention and Trade Center, downtown revitalization (condos and retail), Dock Street redevelopment and the Foss Waterway Public Esplanade from S 17th Street to S 11th Street.

Baseflow at the outfall230 monitoring location is continuous and approximately 0.12 cubic feet per second at one- half-inch in depth. Three sources of the baseflow have been confirmed; however, other sources may be present. Since 2004, groundwater from footings for the Tacoma Convention Center has been pumped to the storm drain. During the 2010 Water Year, investigations led to a discovery of an eight-inch lateral connection on S 11th Street between Commerce and Pacific. This discharge appears to be a continuous flow of clear water at one-fourth-inch in depth. City staff were unable to locate the source of the lateral due to a collapsed pipe. In Water Year 2011, City staff located water discharging into a catch basin (CB#6502144) at 944 Pacific Avenue. At the time, it was noted that 90% of the baseflow in the 11th Street storm line was from this location (City of Tacoma, 2011).

Appendix B. Summary of Results

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Table B-1. Summary of Results.

Sample Identification		Deployment Details						Physical Parameters					Metals (mg/Kg) dw							Organics (ug/Kg) dw			
Sediment Sampling Device	Sample IDs	Stormwater Sediment Sampling Timeframe (TF)	Dates: Fall 2011 and early 2012	No. of Days	No. of storm events	City of Tacoma Rainfall (in)	Volume Carried in Pipe[1] (MG)	Wet Weight (g)	Dry Weight (g)	% Solids	%TOC	% Fines	As	Cd	Cr	Cu	Hg	Pb	Zn	LPAH	HPAH	Total PAH	Total PCB
FD3 Norton	1110056-02	Tacoma TF 1	Oct 6- 17	11	1	0.98	34.8657	71	24	33.3	13.3	--	6.12	0.832	37.4	78.2	--	167	533	--	--	--	--
	1111035-04	Tacoma TF 2	Oct 19 to Nov 8	20	4	1.69	66.6030	14	4	25.5	11.8	--	9.21	1.98	55	163	--	279	1040	--	--	--	--
	1111066-04	Tacoma TF 3	Nov 8 to Nov 30	22	5	3.82	115.7250	44	14	31.8	15.2	--	6.28	1.04	43.2	84.9	0.165	200	521	--	--	--	--
	1201022-01	Tacoma TF 4	Nov 31 to Jan 6	37	7	3.06	123.2992	15	3	18.5	4.13	--	6.66	1.22	61.6	97.7	0.518	1140	770	--	--	--	--
FD3Norton Single Deploy Average							Average	36	11	27.3	11.1		7.1	1.3	49.3	106.0	0.34	446.5	716	--	--	--	--
FD3 Norton-FL	1201022-02	Full Length Deployment	Oct 6 - Jan 6	93				58	17	30.1	11.3	--	6.69	1.03	37.5	96	0.207	192	680	--	--	--	--
FD3 Hamlin	1111035-05	Tacoma TF 2	Oct 19 to Nov 8	20	4	1.69	66.6030	666	497	74.6	1.54	--	4.36	0.314	20.2	31	0.0987 J	55.7	263	753	6094	6847	--
	1111066-05	Tacoma TF 3	Nov 8 to Nov 30	22	5	3.82	115.7250	1312	1072	81.7	0.75	--	3.15	0.216	16.9	19.6	0.0259	32	167	659 J	4104	4763	--
FD3Hamlin Single Deploy Average							Average	989	785	78.2	1.1		3.8	0.3	18.6	25.3	0.03	43.9	215	752.5	5099	5804.75	--
237A Norton	1110056-03	Tacoma TF 1	Oct 6- 17	11	1	0.98	34.8657	67	28	41.3	10	--	6.99	1.08	57.6	92.8	--	131	661	--	--	--	--
	1111035-03	Tacoma TF 2	Oct 19 to Nov 8	20	4	1.69	66.6030	48	26	54.9	6.36	--	4.18	0.592	38.5	53.4	--	90.7	395	--	--	--	--
	1111066-03	Tacoma TF 3	Nov 8 to Nov 30	22	5	3.82	115.7250	27	19	72.2	2.07	--	--	--	--	--	--	--	--	--	--	--	--
	1201022-03	Tacoma TF 4	Nov 31 to Jan 6	37	7	3.06	123.2992	34	22	64	1.93	--	3.68	0.325	22.6	42.1	0.0379	48	218	--	--	--	--
	1202059-01	Tacoma TF 5	Feb 3 to Feb 24	21	4	1.91	87.1788	23	17	72.6	0.83	--	3.83	0.182	24.2	25.1	--	26.3	129	--	--	--	--
237A Norton Single Deploy Average							Average	39.8	22	61.0	4.2		4.7	0.5	35.7	53.4	0.04	74.0	350.8	--	--	--	--
237A Norton-FL	1202059-02	Full Length Deployment	Oct 6 - Feb 24	142				157	71	45.5	12.3	19	5.97	0.868	49.5	90.6	0.088	109	496	4910	44490	49400	402
237A Hamlin	1111035-01	Tacoma TF 2	Oct 19 to Nov 8	20	4	1.69	66.6030	297	159	53.4	6.5	11	4.96	1.57	46.3	67.5	--	94.9	475	2434	19560	21994	291
	1111066-01	Tacoma TF 3	Nov 8 to Nov 30	22	5	3.82	115.7250	820	500	61	5.4	7.9	4.38	0.526	37.7	49.4 J	0.0434	69.3	335	7479	22400	29879	139
	1201022-04	Tacoma TF 4	Nov 31 to Jan 6	37	7	3.06	123.2992	435	230	52.9 J	11.1 J	--	5.09	0.709	37	65.1	0.103 J	75.8	431	3408	28050	31458	--
	1202059-03 split	Tacoma TF 5	Feb 3 to Feb 24	21	4	1.91	87.1788	500	207	41.3	14.7	9.2	7.91	0.614	39.8	61	0.0554	86.9	345	4188	34000	38188	245

Sample Identification		Deployment Details						Physical Parameters					Metals (mg/Kg) dw							Organics (ug/Kg) dw			
Sediment Sampling Device	Sample IDs	Stormwater Sediment Sampling Timeframe (TF)	Dates: Fall 2011 and early 2012	No. of Days	No. of storm events	City of Tacoma Rainfall (in)	Volume Carried in Pipe[1] (MG)	Wet Weight (g)	Dry Weight (g)	% Solids	%TOC	% Fines	As	Cd	Cr	Cu	Hg	Pb	Zn	LPAH	HPAH	Total PAH	Total PCB
	1202059-05 split	Tacoma TF 5	Feb 3 to Feb 24							41.6	8.44	--	6.83	0.522	35	56.2	0.0502	62.9	323	5353	47440	52793	140
237A Hamlin Single Deploy Average							Average	513	274	49.3	8.8	9.37	5.8	0.8	39.2	62.5	0.05	78.0	381.8	4572	30290	34862	203.8
237A Centrifuge Sediment	1202027-09	Tacoma TF 5	10-Feb-12	5 hrs				69	24	34.1	18	--	21.4	2.26	94.9	228	0.275	208	2050	--	--	--	--
	1202035-07	Tacoma TF 5	17-Feb-12	8 hrs				315	137	43.5	19.9	69	13.8	1.6	76.4	145	0.149	180	902	3833	37020	40853	273
237A Centrifuge Sediment Average							Average	192	81	38.8	19.0		17.6	1.9	85.7	186.5	0.21	194.0	1476	3833	37020	40853	273
237A Fuller	1110056-01	Tacoma TF 1	Oct 6- 17	11	1	0.98	34.8657	435 J	382 J	87.8 J	0.49 J	--	2.97 J	0.302 J	16.5 J	20.9 J	--	17.3 J	138 J	--	--	--	--
	1111035-02	Tacoma TF 2	Oct 19 to Nov 8	20	4	1.69	66.6030	702	631	89.9	0.4	0.1	3.73	0.162	20.9	25.3	0.0055 U	18.4	143	142	829	971	4.69
	1111066-02	Tacoma TF 3	Nov 8 to Nov 30	22	5	3.82	115.7250	678	413	60.9	4.4	5.3	3.59	0.358	25.1	39.8	0.0413	117	229	1148	10580	11728	59.1
	1202059-04 split	Tacoma TF 5	Feb 3 to Feb 24	21	4	1.91	87.1788	501	384	76.6	0.95	1.6	4.45	0.22	21.4	32.9	0.0132	28	164	499 J	3960	4459	45.1
	1202059-06 split	Tacoma TF 5								76.8	0.66	--	3.39	0.2	18.6	22.7	0.0098	21.2	139	955	6680	7635	--
237A Fuller Single Deploy Average							Average	579	453	78.4	1.4	2.33	3.6	0.2	20.5	28.3	0.02	40.4	162.6	748	5512	6198	36.3
UnionLPT Hamlin	1111066-06	Spokane TF 1	Nov 22 to 25, 2011	3	1		NC	280	163	58.1	10.8	38	6.88	1.86	32.7	90.6	0.0862	145	679	--	--	--	--
	1202023-01	Spokane TF 2	Jan 27 to 31, 2012	4	1		NC	364	207	56.9	8.72	42	5.65	0.952	27.4	71.9	0.0538	96.4	479	1944	8092	10036	191
	1203042-01	Spokane TF 3	Feb 28 to Mar 2, 2012	3	1		NC	175	108	61.9	9.36	--	5.52	1.22	26.3	67.3	0.0388	90.8	432	1966	7219	9185	166
Union Average			Average	4	1			273	159	59.0	9.6	40	6.0	1.3	28.8	76.6	0.06	110.7	530.0	1955	7655.25	9610.25	178.5

1: Flow values are estimates due to tidal influences.

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Baseflow: Groundwater discharge to a surface stream or river. The component of total streamflow that originates from direct groundwater discharges to a stream.

Fines: Particulates pertaining to the size range assigned to clay plus silt (0-0.062um).

In-line device: Particulate capture device placed directly within the drainage network.

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

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

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.

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

BC	British Columbia, Canadian Province
CSL	Cleanup Screening Level
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
HDPE	High-density polyethylene
HPAH	High-molecular-weight polycyclic aromatic hydrocarbon
LISST	Laser In-Situ Scattering and Transmissometry particle-size-distribution analyzer
LPAH	Low-molecular-weight polycyclic aromatic hydrocarbon
MEL	Manchester Environmental Laboratory
OC	Organic carbon
PAH	Polycyclic aromatic hydrocarbons
PBT	Persistent, bioaccumulative, and toxic

PCB	Polychlorinated biphenyl
QA	Quality assurance
SOP	Standard operating procedure
SQS	Sediment Quality Standard
SSPM	Stormwater suspended particulate matter
TOC	Total organic carbon
TSS	Total suspended solids

Units of Measurement

dw	dry weight
ft	feet
g/d	grams per day
g/cm	grams per centimeter
L/min	liters per minute
MGD	million gallons per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)