Program Effectiveness Report

Street Sweeping for Water Quality

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Foreword

This document serves as the City of Seattle's (City) 2011 monitoring report as required by Special Conditions S8.E, Program Effectiveness Monitoring, of the 2007 National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit (Permit). The Permit was effective on February 16, 2007 and modified on June 17, 2009 and September 1, 2010 by the Washington Department of Ecology (Ecology) under the NPDES and State Waste Discharge General Permits for discharges from Large and Medium Municipal Separate Storm Sewer Systems.

The permit program effectiveness monitoring component requires the City to select two specific aspects of the Stormwater Management Program to evaluate; the effectiveness of a targeted action and the effectiveness of achieving a targeted environmental outcome. This monitoring is intended to improve stormwater management efforts by providing a feedback loop to help determine if a stormwater management program element is meeting the desired environmental outcome.

The potential impact of urban stormwater runoff on the water quality of receiving waters is of great concern in the Seattle area. While new development and redevelopment may have a large number of options for providing water quality treatment through structural controls, existing developed areas have limited choices for retrofitting their stormwater systems. Thus, nonstructural measures, also known as source control, offer perhaps the greatest potential for improvement of water quality. Roads and other transportation related surfaces make up 26 percent of the land use within the City; the permit requires that the City establish practices to reduce stormwater impacts associated with runoff from paved surfaces. Street sweeping with newer technology sweepers is one of the source control tools available to meet this permit requirement and the City has recently expanded its sweeping program, with a focus on removing pollutants from roadways that discharge to the City's Municipal Separate Storm Sewer System (MS4). Because of this, the City has chosen to build upon the "Seattle Street Sweeping Pilot Study" (SPU & Herrera 2009) and evaluate the program effectiveness of street sweeping for both required aspects:

- **Targeted action** - Does street sweeping result in improvements in stormwater quality and quality of sediments in stormwater discharges or both? This aspect will evaluate the effectiveness of regenerative air street sweeping technology at a frequency of every two weeks to potentially provide treatment at a level similar to structural stormwater BMPs by reducing the quarterly average street dirt pollutant load 60 percent for fine particles (less than 250 microns in diameter).

- **Targeted outcome** - Does street sweeping reduce the discharge of certain pollutants below a targeted annual load amount? This aspect will be evaluated with a spreadsheet model that predicts a targeted annual load reduction, using total suspended solids as a surrogate pollutant, for varying conditions, such as sweeping frequency, sweeping velocity, and parking enforcement compliance.

The targeted action aspect is provided in this document. The targeted outcome aspect is documented in a spreadsheet model.

1 Summary

This study, which was conducted to meet the program effectiveness monitoring requirement (S8E) in the 2007 Phase I National Pollutant Discharge Elimination System (NPDES) Municipal Permit, examines the potential for regenerative air street sweeping technology to provide a level of treatment similar to structural stormwater Best Management Practices (BMPs). The application of street sweeping in a highly built-out urban area, like Seattle, has the potential to be a cost-effective and practical non-structural BMP that may significantly reduce pollutant loading to nearby receiving water bodies from potentially toxic transportation-derived contaminants.

Determining the effectiveness of street sweeping using regenerative air sweepers, which captures the full size spectrum of potential pollutants – from silt to gross solids, when compared to structural BMPs, which typically capture solids suspended in the water column, is difficult due to the following factors: other studies (USGS 2007) have not been able to show a direct correlation between street sweeping and a reduction of potential pollutant concentrations in the stormwater water column; BMP basic treatment performance standards are concentration-based for total suspended solids (TSS) within the water column; and finally, street sweeping performance is variable and sampling results are solids-based.

However, the effectiveness of both structural BMPs and street sweeping is dependent on the particle size distribution (PSD) of stormwater solids, which also affects the fate and transportation of potential pollutants associated with the particulate matter (PM) and therefore the impact to the beneficial uses of the receiving environment. Therefore, an understanding of the PSD may be used to help compare the effectiveness of street sweeping to structural stormwater BMPs.

By assuming that: (1) particles with a diameter less than 250 microns (µm) will be suspended in the water column (see section 2.3.2) once washed off the street surface and (2) a removal efficiency of 60 percent of the street dirt load meets regulatory performance criterion for typical Seattle conditions (see section 4.2) we can compare street sweeping, which typically accounts for performance by measuring the pollutant load removed across the entire size spectrum (from silt to gross solids), with stormwater structural BMPs, which typically account for performance by measuring the suspended solids removed from the water column.

In order to show that street sweeping using a regenerative air sweeper on a biweekly basis has the potential to reduce the street dirt load at a level similar to structural stormwater BMPs, archived quarterly composite street dirt and sweeper waste samples collected during the "*Seattle Street Sweeping Pilot Study (referred to as pilot study hereafter)" (SPU & Herrera 2009)* were thawed, split into four particle grain size fractions (silt and clay (<75 µm), fine sand (75 to 250 µm), coarse to medium sand (250 to 2,000 µm), and gravel (> 2,000 µm)) and each fraction was analyzed for seven metals (arsenic, cadmium, chromium, copper, lead, silver, and zinc).

- The pilot study samples were collected at two residential basins (West Seattle and Southeast Seattle) from June 20, 2006 through June 19, 2007 and one industrial basin (Diagonal Duwamish) from November 24, 2006 through June 15, 2007. The split samples were analyzed April and May of 2008 from excess sample volume that had been frozen and archived during the pilot study.

- Street dirt represents the material potentially available to wash off the street into the drainage system, blow off, or be picked up by a sweeper. During the pilot study, three street dirt samples were collected every four weeks, one from each of the three basins using a vacuum. The individual samples were weighed and analyzed for moisture before combining into a basin quarterly composite sample that was analyzed for grain size and pollutant concentrations.

- Sweeper waste samples represent the material picked up by a regenerative air sweeper sweeping between four and six miles per hour and a biweekly frequency over three basins. Each basin has two routes, swept on opposite weeks, for a total of six unique routes. Three sweeper waste samples were collected every four weeks during the pilot study from material representing six routes swept twice

during the four-week period. The individual samples were weighed and analyzed for moisture before combining into a basin quarterly composite sample that was analyzed for grain size and pollutant concentrations.

This analysis of the archived samples collected during the pilot study indicate that under average quarterly conditions there is inferred potential for regenerative air street sweeping technology implemented on a biweekly basis to provide a level of treatment similar to structural BMPs by reducing the stormwater suspended solids, chromium, copper, lead, and zinc load by 60 percent for particle diameters less than fine sand as well as all particles combined.

- The median quarterly average sediment load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for silt and clay (<75 µm), fine sand (75 to 250 µm), coarse to medium sand (250 to 2,000 µm), and gravel (> 2,000 µm), with p-values of 0.14, 0.25, 0.91, and 0.99, respectively.

- For fines <250 µm, the median quarterly average metal load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.12, 0.21, 0.23, and 0.073, respectively).

- For all particle size classes combined, the median quarterly average metal load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.20, 0.09, 0.41, and 0.23, respectively).

Given the findings, street sweeping with regenerative air sweepers is an effective stormwater management tool for street dirt load removal and it is recommended:

- That Seattle Public Utilities continue to support and grow the “Street Sweeping for Water Quality Program,” which kicked off February 22, 2011, as part of the Stormwater Management Program.
- That additional studies be considered to determine the site specific conditions and sweeping operation characteristics needed to maximize the pollutant load removed by sweeping in the most cost effective manner. Study variables may include frequency, seasonality (in particular, dry season, leaf season, and wet season), and sweeping velocity.

2 Introduction

This study was conducted to meet the program effectiveness monitoring requirement (S8E) in the 2007 Phase I National Pollutant Discharge Elimination System Municipal Permit, which is intended to improve stormwater management efforts by evaluating at least two stormwater management practices that significantly influence the success of our stormwater controls. Ecology's purpose is to determine the effectiveness of the Stormwater Management Program (SWMP) at controlling a stormwater related problem directly addressable by targeted actions in the SWMP.

This study, implemented to meet the requirements of the permit, builds on the foundation established by the "Seattle Street Sweeping Pilot Study" using archived samples collected during the last two quarters of 2006 and first two quarters of 2007. This study does not include the collection of any new data, but rather analysis of archived samples that were previously submitted to Analytical Resources, Inc. (ARI). See Herrera (2006) and SPU & Herrera (2009) for additional information and study details.

The Seattle Street Sweeping Pilot study showed that regenerative air technology street sweeping is a practical tool in a fully built-out urban environment with the promise to reduce the potential pollutant load that may otherwise be transported to the receiving water. Other studies found similar results:

- Relatively high quantities of pollutants were found in street sweeps in all catchments suggesting street sweeping as an effective measure to control diffuse pollution (Muhammad et al 2006).
- Depree (2008) confirmed environmental concerns regarding the levels and mobility of zinc contaminants in catch basin and street sweeping samples in toxicity tests on the fresh water alga *Psuedokirchneriella subcapitata*.

Street sweeping using regenerative air or vacuum technology is increasingly given credit for reducing the potential pollutant load. Two examples of how street sweeping is being incorporated into Stormwater Management programs include:

- Street sweeping is considered an acceptable maintenance practice for meeting the State of Wisconsin National Pollutant Discharge Elimination System (NPDES) stormwater performance standard for redevelopment. The rule (NR 216.07(6)(a)) requires certain municipalities to develop a stormwater management program designed to achieve compliance with the developed urban area performance standard, e.g., to the maximum extent practicable, implement a 20 percent and a 40 percent reduction in total suspended solids (TSS) in runoff that enters waters of the state as compared to no controls, by March 10, 2008 and March 10, 2013, respectively (Rasmussen 2010).
- Work to develop a Florida-based metric or "yardstick" to reduce nutrient loading from municipal separate storm sewer systems includes street sweeping (Sansalone, 2011).

Street sweeping has been shown to be a cost-effective operation and maintenance source control Best Management Practice (BMP):

- The City of Seattle Pilot Study (2009) found that street sweeping has the potential to be a cost effective strategy for removing sediment and associated pollutants from roadways in the City of Seattle and is likely to be more cost-effective than annual catch basin cleaning or stormwater treatment.

- Sansalone (2011) reports the cost to remove particulate matter (PM) on a $/pound basis in Florida ranges from 0.10, 0.70, 3, and 41 for street sweeping, catch basin cleaning, hydrodynamic separator, and structural BMPs, respectively.

Determining the effectiveness of street sweeping compared to structural BMPs is difficult:

- Other studies (USGS 2007) have not been able to show a direct correlation between street sweeping and a reduction of potential pollutant concentrations in the stormwater water column.

- BMP basic treatment performance standards are concentration-based for total suspended solids (TSS) within the water column under the conditions during the sampling event. Street sweeping samples are collected as solids and include the entire particle size fraction, from TSS to gross solids. Stormwater samples are collected over the course of the sampling event. Studies have concluded that automatic samplers may not provide representative samples of stormwater across all particle sizes(Kim et al, 2008).

- And finally, street sweeping performance is variable and may change depending on the following factors:

    - Street dirt characteristics (load and solids size distribution, which vary over the course of the year)
    - Street surface characterization (slope, roughness, curbs, parking density, parking compliance)
    - Precipitation characteristics (frequency, intensity, and duration of rainfall)
    - Sweeping frequency
    - Sweeper pickup efficiency under the given conditions (including equipment maintenance, operator training, etc.).

However, comparing particle size distributions presents an alternative evaluation methodology for street sweeping performance that may allow for comparison to structural stormwater BMPs:

- Researchers (Liebens 2001, Breault et al 2005) have shown mechanical broom street sweepers to be ineffective at removing fine particles less than 250 micron (μm) available on the roadway as street dirt. This may influence the relative depletion and enrichment of metals in sweeper waste and catch basin sediment, respectively under the following assumptions:

    - the sweeper waste metal concentrations will be less than street dirt metal concentrations as finer particles generally have higher concentrations due to their surface area to volume ratio.
    - the sweeper waste metal concentrations will be less than catch basin sediment metal concentrations as the fine material not picked up by the sweeper will wash off into the catch basins.
    - Minimal scour of previously captured sediment occurs.

- Conversely, if regenerative air street sweepers are effective at removing available street dirt fine PM with a diameter less than 250 micron (μm), we expect to see similar particle size distributions in sweeper waste and street dirt, similar contaminant concentrations in catch basin sediment, street dirt, and sweeper waste, and similar loads in sweeper waste removed and available street dirt given the underlying assumptions. If this is the case, we assume that regenerative air street sweeping provides treatment at a level similar to structural stormwater BMPs.

2.1 Background

This work follows up on the City of Seattle Street Sweeping pilot study (pilot study) by (1) reviewing the particle size distribution data collected during the pilot study and (2) conducting additional analysis of metals concentrations by four particle size fraction classifications; clay and silt, fine sand, coarse to medium sand, and gravel for catch basin, street dirt, and sweeper waste samples collected during the pilot study.

The particle size distribution (PSD) of stormwater-borne solids affects the fate and transportation of potential pollutants associated with the particulate matter (see WERF (2007) and Sansalone et al (2008)). Improving the understanding of this dynamic process allows stormwater managers to better determine where investments should be placed to provide the most cost-effective environmental benefits.

Following the methodology presented by Kim and Sansalone (2008), the term particulate matter (PM) is used to differentiate materials (especially fine PM) that are transported in runoff but not always be present in the form of individual discrete particles, but rather may be aggregated as PM.

Researchers have used many particle size classification schemes. The classification system used in this study (Table 1) follows that already implemented by other City of Seattle projects and follows the general principles outline by WERF (2007) and Sansalone et al (2008).

Table 1. Solids classification schemes.

Particle Size Range (µm)	**< 1**	**≥1 to<2**	**≥2 to <4**	**≥4 to <25**	**≥25 to <62.5**	**≥62.5 to <75**	**≥75 to <250**	**≥250 to <2000**	**≥2000 to <4750**	**≥4750 to <5000**	**≥5000 to <64000**
Wentworth Classification	Colloid	Clay		Silt		Fine sand		Coarse to medium sand	Gravel		
Sansalone (2008)	Dissolved	Suspended			Settleable (by Imhoff cone)		Sediment				Grit
WERF (2007)	Dissolved		Fine Solids (silt, coarse clay, organic fines, phytoplankton)				Coarse Solids (very fine sand, very fine gravel, detritus)				Gross Solids
This Study		Clay and silt					Fine sand	Coarse to medium sand	Gravel		

In 2007, WERF proposed a stormwater-borne solids size classification scheme with the intent of providing a consistent system for defining the major classes of stormwater solids and related implementable protocols for sample collection, handling, and analysis. This classification scheme was also intended to aid in the design and selection of appropriate BMPs based on their unit processes and lead to a better understanding of the effects stormwater solids have on the beneficial uses of the receiving environment (Figure 1).

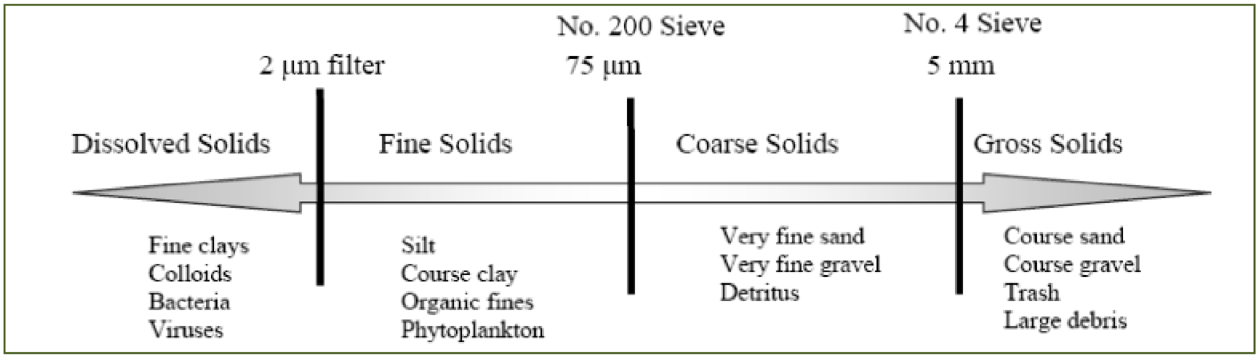

Figure 1. Solids size classification diagram (proposed by WERF 2007).

WERF (2007) provided the following definitions:

- **Gross solids** are defined as the solid material that can be captured on a 5 mm screen. Gross solids can further be divided into three classifications; litter, debris, and coarse sediment. Litter includes human derived trash, such as paper, plastic, Styrofoam, metal, and glass. Debris consists of organic material including leaves, branches, seeds, twigs, and grass clippings. Coarse sediments are inorganic breakdown of soils, pavement and building material

- **Coarse solids** are defined as the solid material greater than 75 µm and less than 5 mm. These solids are associated with sedimentation that may destroy habitat, impact benthic organisms, and transport toxic elements into the ecosystem. Often, particles larger than 75 µm are not effectively collected using automatic water quality samplers therefore a combination of bedload samplers and autosamplers may be needed to sample this size range.

- **Fine solids** are the material that pass through the No. 200 sieve (75 µm) but retained by a 2 micron filter. Fine solids are commonly transported as suspended solids and attributed to increased turbidity, thought to transport harmful toxins into the ecosystem, and increase embeddedness characteristics. The 2 µm filter is selected because smaller size filters tend to clog and the residue itself affects the size of material that is retained above the filter. In addition, the 2 µm particle size represents the lower limit of particle size that will normally settle out in a typical stormwater detention pond.

- **Dissolved solids** are defined as the particles that pass through a 2 micron filter (SM 2540C). Although conventionally defined as retained by a 0.45 µm filter, the change is recommended by WERF because the filter size used to distinguish "TSS" from "Total Dissolved Solids (TDS)" is not consistent. An inconsistent filter size is a problem because the use of a standard 2 micron filter will produce different results than using a 0.45 micron filter, but any size smaller than 2 µm is acceptable according to the APHA Standard methods for the Examination of Water and Wastewater (SM 2540) test protocol.

Sansalone et al (2008) used a similar classification system proposed by WERF, but modified to more clearly address the effectiveness of structural treatment BMPs designed for settling (Table 1).

Stormwater-borne solids may impact the receiving waters and can pose a physical problem affecting geomorphology and ecologic habitats in addition to potentially transporting harmful chemicals from the urban environment into the natural ecosystems (WERF 2007). The solidsPSD is influenced by catchment geometry, land use and land use activities such as traffic, as well as geology and weather (wind and precipitation). The PSD and metal partitioning potentially also change over the course of an individual storm event (Tiefenthaler et al 2007).

- PSD influences the transport and deposition of stormwater-borne solids.

- PSD influences the potential impact of stormwater-borne solids on habitat.
- PSD influences the potential impact of stormwater-borne solids on aquatic life.
- PSD influences the performance of both street sweeping and structural treatment BMPs.

2.1.1 PSD INFLUENCES THE TRANSPORT AND DEPOSITION OF STORMWATER-BORNE SOLIDS.

The pathways of roadway pollutants to the receiving water can be placed into two broad categories:

- Atmospheric dispersion with consequent wet and dry deposition.
- Transport via stormwater with subsequent dispersion of material depending upon environmental conditions. Coarser PM can be retained in a drainage system to a significant degree, impairing the conveyance capacity with the potential for eventual transport to receiving water during extremely large storm events (Kim et al 2008).

Temporal and spatial variation in rainfall may have significant impact on the rate and distribution of particle wash off. Kayhanian and Stenstrom (2008) characterized stormwater runoff as either mass-limited or flow-limited. They defined mass-limited as an event where rainfall duration exceeds available PM supply and flow-limited runoff as an event where rainfall duration is insufficient to remove the available runoff PM. Shaw et al (2010) also proposed a pollutant buildup/wash-off model that assumed a constant mass available for wash-off.

The fate of road transport-derived materials and contaminants is dependent upon the nature of the material and the contaminant. Stormwater particles are, at any given time, buoyant, suspended, settled or in the process of settling. The varying size, shape, density, and composition of stormwater particles affect the types and relative concentrations of pollutants sorbed to or absorbed within stormwater particles (WERF 2007). In addition, the organic content plays a significant role in particle density, settling velocity, and pollutant-binding tendencies (DeGroot 2008).

After discharge to the receiving environment, the PM and potential associated pollutants partition into the water column, the sediments, and the biota (see Figure 2).

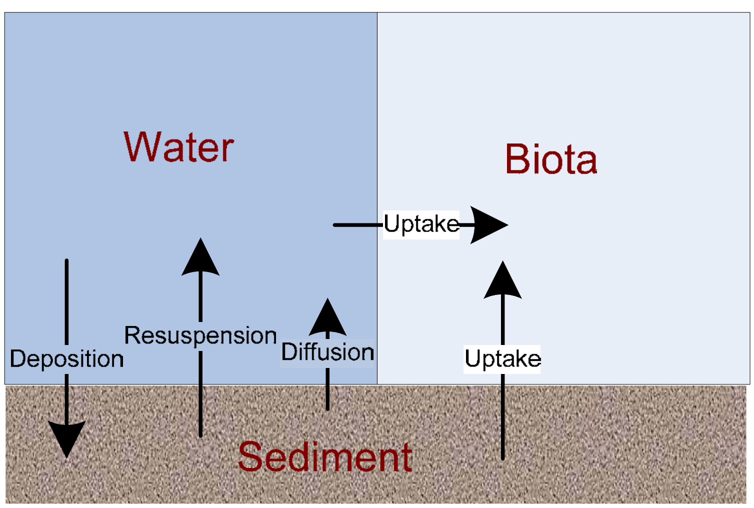

Figure 2. Fate of stormwater pollutants within the receiving environment.

Changes to the receiving water characteristics, such as velocity, temperature, and chemistry in response to stormwater discharge, a transient effect, may result in PM changes and pollutant partitioning changes.

- Particulates are deposited in the sediments and may later resuspend. Chadwick et al (2004) found that sediments are a key endpoint for copper in San Diego Bay. Water column concentrations were overestimated by as much as a factor of five without considering the role settling plays in the fate of copper.

- Filter feeding organisms (such as may flies, clams, oysters, anemones, and even whales) and sediment ingesting organisms (such as worms) uptake contaminants from the water column and sediments. The contaminant is generally concentrated as it moves up the food chain.

There is potential that stormwater PM distributed throughout the drainage system may act as a source or sink for pollutants depending on its physical and chemical properties and quantifying the complete pollutant load through all size fractions provides several advantages (Sansalone 2007):

- While larger particles have been typically considered to have lower pollutant concentrations, examination of the entire gradation indicates that pollutant mass can be distributed across the entire particle size gradation with a significant amount of pollutant mass potentially associated with coarser fractions when such fractions dominate the gradation.

- Both large and small particles can carry a significant heavy metal load. In general, small particles (< 150 μm) carry a more significant nutrient load. Polychlorinated Biphenyls (PCB's) and Polycyclic Aromatic Hydrocarbons (PAHs) tend to associate with organic material, much of which is found in finer particle fractions, but portions of which have been found in larger (>100 μm) fractions.

- Whether this coarse PM inventory resides on urban surfaces or in conveyance systems, it is generally more labile, or chemically unstable, than finer PM fractions.

- Urban PM in conveyance systems is subject to rainfall leaching, runoff leaching in conveyance systems, or leaching through cyclic redox conditions in BMPs that detain runoff between wet weather events. Coarse PM can also act as temporary reservoirs as chemically enriched sediments or enriched BMP sludge.

2.1.2 PSD INFLUENCES THE POTENTIAL IMPACT OF STORMWATER BORNE-SOLIDS ON HABITAT.

Urban land uses have been positively correlated with fine sediment and embeddedness characteristics, which have damaging effects on stream ecology (Sylte et al 2002). Embeddedness is defined as the degree to which fine sediments surround coarse substrates on the surface of a streambed and is important to both physical and biological stream functions. From Sylte et al (2002):

- Physically, as stream substrates become more embedded, the interstitial space between particles is reduced, thus effectively reducing streambed roughness and altering channel bedform and hydraulics.

- Biologically, reductions in both permeability and inter-particle dissolved oxygen directly impact spawning for many fish species; decreases in the interstitial space between particles limit the available area and cover for small fish, macroinvertebrates, and periphyton; and shifts to finer materials in particle size distributions can alter biotic communities by reducing species diversity and density.

The National Marine Fisheries Service (NMFS) Matrix of Pathways and Indicators (1996) considers streams with a dominant substrate of gravel or cobble, or streams with embeddedness <20 percent, to be in a properly functioning condition.

2.1.3 PSD INFLUENCES THE POTENTIAL IMPACT OF STORMWATER BORNE SOLIDS BIOAVAILABILITY

Concentration is an indication of the potential magnitude of the pollutant's bioavailability. Actual bioavailability is dependent on both physical and chemical form when the organism is exposed. The fate, mobility, and bioavailability of metals is dependent on the speciation, or chemical –physical form, of the metal in sediment and water. Metals present in stormwater can be divided into a number of fractions including: the soluble metal in the water column and sediment pore water; metal-precipitates; metal sorbed to clays, hydrous oxides and organic matter; and metals within the matrix of sediment minerals. Table 2 provides the relative mobility of different metal species.

Table 2. Relative mobility and availability of trace metals (from USGS 1995).

Metal species and association	Mobility
Exchangeable (dissolved) cations	High . Changes in major cationic composition (e.g. estuarine environment) may cause a release due to ion exchange.
Metals associated with organic matter	Medium/high. Strongly dependent on environmental conditions. Under oxygen-rich conditions, oxidation off sulfide minerals leads to release of metals.
Metals associated with Fe-Mn oxides	Medium. Changes in redox conditions may cause a release but some metals precipitate if sulfide mineral present is insoluble.
Metals fixed in crystalline phase	Low. Only available after weathering or decomposition.

Metal species dissolved in water may occur as free ions (aquo-ions) or as complexes (EPA 2007). The dissolved fraction is defined as a measurement of all the metal passing through a 0.45 µm filter and includes both fine (<0.45µm) particles and ions. Thus the dissolved metal is always greater than and should not be considered to be the same as the ionic metal when fine (<0.45 µm) metal particulates are present. Ionic metal species are commonly the most bioavailable form to aquatic organisms (USGS 1995).

Bioavailability is dependent on a complex set of factors that may vary seasonally and temporally and be inter-related, including receiving water hydrology (volume, water velocity, and duration), receiving water chemistry (pH, redox potential, temperature, total organic content (both particulate and dissolved fractions), and suspended particulate content) (USGS 1995). Figure 3 presents a generalized model framework for factors affecting bioavailability.

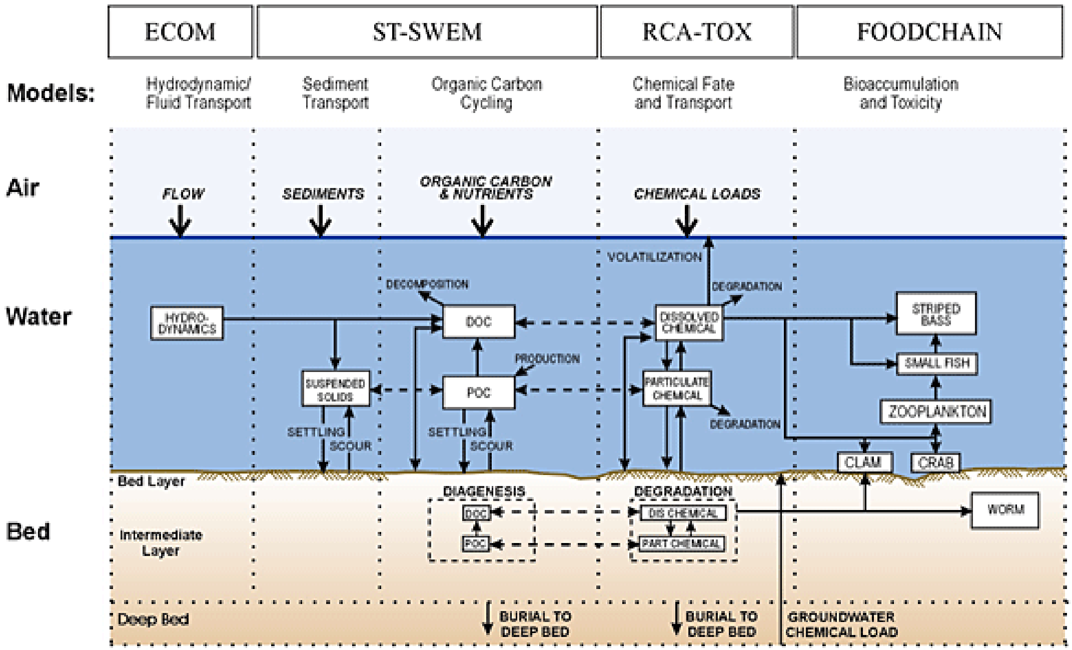

Figure 3. A generalized model framework for chemical fate and transport in an aquatic system (from Miller et al 2011).

The presence of fine PM may reduce metal bioavailablity by providing more total surface area for adsorption and therefore decreasing the concentration of dissolved metals. Stormwater-borne trace metals typically are associated with particulates to varying degrees, depending on the metal and the size distribution of suspended solids in the stormwater runoff. Paulson (1993) found that the four most important factors controlling the distribution of metals among dissolved and bioavailable fractions include: suspended solid types and concentrations, pH, total metal concentrations, and dissolved organic carbon concentration and character.

Gnecco et al (2008) modeled metals partitioning and metals complexation using study results from three monitoring sites. They found that for the three metals analyzed zinc was potentially the most toxic among the dissolved metal species; zinc preferred the ionic form across all monitoring results with copper and lead showing an affinity to form carbonate species and dissolved organic matter complexes. The bioavailability of metal species decreases moving from the ionic form to weakly organic/inorganic species to strongly bound complexes.

Figure 4 presents the relationship of TSS concentrations with f_d (dissolved fraction) for data collected by Gnecco et al (2008) and shows the stronger positive relations of dissolved metals with TSS concentrations for a storm event with low TSS, 13 mg/L (18 February 2006) and an event with high TSS, 65 mg/L (21 October 2006).

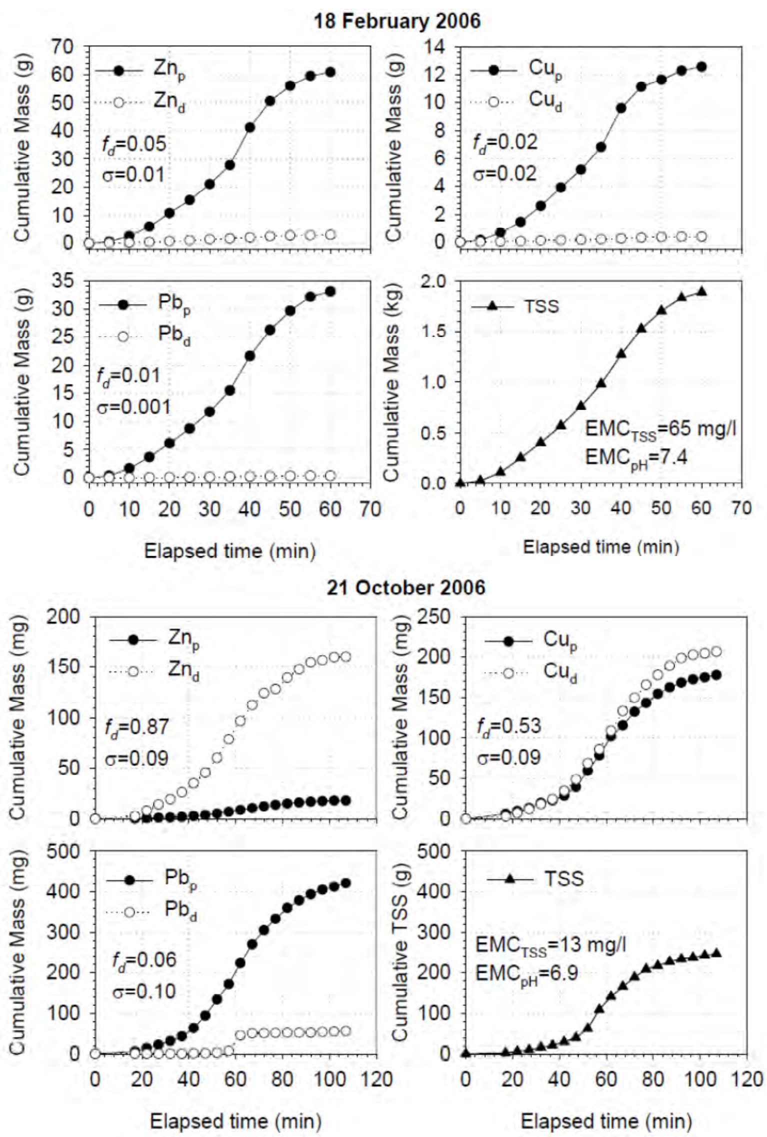

Figure 4. Cumulative mass delivery of dissolved (Med) and particulate (Mep) metals fractions for two events monitored by Gnecco et al (2008).

Typical structural BMPs remove the particulate-bound metal fraction through the process of settling and sedimentation. Therefore, the bioavailable reduction by structural BMPs is limited by the degree to which pollutants associate with particles and the efficiency with which the BMP removes the PM, both of which can vary with particle size (Caltrans 2003).

Seattle stormwater characterization data (SPU 2010) indicate that approximately one third of both copper and zinc would not be removed by a structural BMP that uses settling and sedimentation as primary pollutant removal processes (e.g., the dissolved fraction would not be removed). Table 3 presents Seattle stormwater characterization sampling results collected under the 2008 Phase I MS4 NPDES permit (SPU 2010). The median dissolved fraction (f_d) for copper and zinc are very similar at residential sites (0.27 and 0.26) and commercial sites (0.40 and 0.38), but less similar at the industrial sites (0.29 and 0.39). The median dissolved fraction (f_d) for copper and zinc for all land uses in Seattle (0.35 and 0.36) are much higher than the event evaluated by Gnecco et al (2008) (0.02 and 0.05) having a similar TSS concentration (65 mg/L versus 49 mg/L for Seattle).

Table 3. City of Seattle NPDES stormwater characterization water year 2010 sampling results showing partitioning between dissolved and particulate-bound phases (extracted from SPU 2010).

Land Use	Parameter	Fraction	Median	25th Percentile	75th Percentile	Count
Residential	TSS	Total (mg/L)	50.9	33.6	72.4	11
	Copper	Dissolved (ug/L)	4.2	2.7	7.3	11
		Particulate-bound (ug/L)	8.4	6.4	13.3	11
		f_d	**0.27**	**0.20**	**0.53**	11
	Zinc	Dissolved (ug/L)	11.0	11.0	18.5	11
		Particulate-bound (ug/L)	31.0	24.5	44.0	11
		f_d	**0.26**	**0.21**	**0.44**	11
Commercial	TSS	Total (mg/L)	44.2	35.0	50.	12
	Copper	Dissolved (ug/L)	18.2	12.0	26.7	12
		Particulate-bound (ug/L)	32.6	23.6	33.9	12
		f_d	**0.40**	**0.32**	**0.45**	12
	Zinc	Dissolved (ug/L)	52.5	36.5	62.0	12
		Particulate-bound (ug/L)	71.5	58.5	85.0	12
		f_d	**0.38**	**0.35**	**0.52**	12
Industrial	TSS	Total (mg/L)	69	46.0	90	11
	Copper	Dissolved (ug/L)	4.6	4.4	6.7	11
		Particulate-bound (ug/L)	15.3	9.9	18.5	11
		f_d	**0.29**	**0.25**	**0.39**	11
	Zinc	Dissolved (ug/L)	47.0	44.5	65.5	11
		Particulate-bound (ug/L)	84.0	65.5	111.5	11
		f_d	**0.39**	**0.31**	**0.53**	11
All Land Uses	TSS	Total (mg/L)	49.2	36.4	72.8	34
	Copper	Dissolved (ug/L)	7.1	4.32	15.9	34
		Particulate-bound (ug/L)	15	8.92	31.6	34
		f_d	**0.35**	**0.24**	**0.47**	**34**
	Zinc	Dissolved (ug/L)	40	17	53.8	34
		Particulate-bound (ug/L)	62	32	89.2	34
		f_d	**0.36**	**0.28**	**0.51**	**34**

Cadmium, lead, and mercury sample results are not included due to low detected concentrations.
Particulate bound=total concentration – dissolved concentration
f_d is dissolved fraction = dissolved metal concentration/total metal concentration

The coarser PM presents a potential risk of long-term impact to beneficial use. Typically, the impact to the beneficial use from a bioavailable perspective has been focused on the finer-sized PM, in particular metals associated with the suspended PM, which are mobile and represent an acute bioavailability concern in receiving waters (Sansalone, 2010). Although the dissolved and suspended fractions of a metal are more reactive and immediately bioavailable, Sansalone (2010) found that the coarser PM and associated metal in unmaintained structural stormwater BMP operations and urban drainage infrastructure represent a significant load inventory and a potential long-term source of leachable metals to receiving waters.

Depree (2008) performed fresh water leaching tests on eight samples, four street sweeping waste samples and four catch basin sediment samples from three different cities to determine the potential for reuse of street sweepings and catch basin solids. Methodology similar to the Toxic Characteristic Leaching Procedure (TCLP) test was used, where a 20:1 ratio of solvent (typically 800 mL of de-ionized water to 40 grams of material) with agitation for approximately 24 hours.

Median fresh water leachate concentrations in all samples (n=8) of lead (12 µg/L), copper (66 µg/L) and zinc (304 µg/L), were much lower than the corresponding TCLP concentrations (115, 120 and 6200 µg/L, respectively). The percentage of heavy metals mobilized by fresh water, relative to TCLP solution, was 5 percent, 35 percent, and 7 percent for lead, copper, and zinc, respectively. The reason for the higher percentage of copper mobilized by freshwater leachate was presumably because of the stronger affinity of copper for dissolved organic carbon (DOC) – supported by the high correlation coefficient (r^2) of 0.74 for these parameters.

Dupree found median sweeper waste fresh water leachate concentrations (n=4) of lead (12 µg/L), copper (111 µg/L) and zinc (453 µg/L) were greater than median catch basin fresh water leachate concentrations (n=4) of lead (11 µg/L), copper (24 µg/L) and zinc (248 µg/L).

2.1.4 PSD INFLUENCES THE PERFORMANCE OF BOTH STREET SWEEPING AND STRUCTURAL TREATMENT BMPS.

Typically, performance of a stormwater structural treatment BMP is measured by a reduction in the finer, total suspended solids (TSS) size fraction. This is appropriate to measure efficiency, but does not provide an indication of the significance of the environmental benefit realized (Lin, 2003) nor allow for easy comparison against street sweeping where performance is based on removing the entire size fraction gradation.

The structural stormwater BMP treatment performance standards defined by Ecology (2008) include:

- **Pretreatment** is intended to achieve 50 percent removal of fine (50 micron-mean size) and 80 percent removal of coarse (125-micron-mean size) total suspended solids for influent concentrations greater than 100 mg/L, but less than 200 mg/L. For influent concentrations less than 100 mg/L, the facilities are intended to achieve effluent goals of 50 mg/L of fine and 20 mg/L of coarse total suspended solids. Pretreatment devices should be able to remove at least 80 percent of OK-110 particles (mean particle size of 106 µm and 99.9 percent less than 250 µm) at the water quality design flow rate.

- **Basic treatment** should achieve 80 percent removal of total suspended solids for influent concentrations ranging from 100 to 200 mg/L. For influent concentrations greater than 200 mg/L, a higher removal efficiency is appropriate. For influent concentrations less than 100 mg/L, the facilities should achieve an effluent goal of 20 mg/L total suspended solids. Basic treatment devices should be able to remove at least 80 percent of Sil-Co-Sil 106 particles (mean particle size of 23 µm and 100 percent less than 212 µm) at the water quality design flow rate.

- **Enhanced treatment** for metals is intended to remove 30 percent of the dissolved copper fraction for influent concentrations ranging from 5 to 20 µg /L and 60 percent of the dissolved zinc fraction for influent concentrations ranging from 20 to 300 µg/L at the design water quality flow (Ecology 2011).

Ecology previously defined total suspended solids as all particles smaller than 500 microns in diameter when applying treatment performance goals (Ecology 2008). The larger particles excluded include litter, debris, and other gross solids exceeding 500 microns (larger than medium-sized sand).

2.2 Purpose

The primary objective of the study is to *determine if the targeted action of regenerative air street sweeping has the potential to provide a level of treatment similar to structural stormwater BMPs.*

The pilot study was not designed to evaluate the effectiveness at meeting the Ecology BMP performance standard for removing 80 percent of the average annual load. However, with the addition of metal distribution by size fraction data, we can analyze the performance of street sweeping to remove particles of different diameters.

The underlying assumption is that if the street sweeping pickup efficiency for PM less than 250 μm is equivalent to structural BMPs, then street sweeping will provide equivalent treatment on an average annual load basis when compared to structural BMPs (assuming adequate sweeping frequency and BMP maintenance for the basin conditions).

2.3 Design

The study design is briefly described below. Please refer to the Quality Assurance Project Plan (QAPP) for additional information.

The study is designed to answer two questions:

When regenerative air street sweeping technology implemented under the conditions described in the pilot study is compared to typical structural BMPs:

- *Do regenerative air street sweepers provide comparable reduction in the stormwater load from metals associated with a particle size less than fine sand?*
- *Do regenerative air street sweepers provide comparable reduction in the bulk of the stormwater metals loading?*

2.3.1 Significance

The application of street sweeping in highly built out urban areas has the potential to be a cost-effective non-structural BMP that may significantly reduce pollutant loading to nearby receiving water bodies from potentially toxic transport-derived contaminants.

The particle size distribution (PSD) of stormwater-borne solids affects the fate and transportation of potential pollutants associated with the particulate matter and therefore the impact to the beneficial uses of the receiving environment.

Improving the understanding of the PSD assists the stormwater manager to select the most appropriate BMP, whether street sweeping or a structural treatment BMP, to address the issue of concern, whether it be habitat loss, pollutant loading, human health, or aquatic life, with the most cost-effective solution.

2.3.2 Hypotheses to be Tested

The two questions and the corresponding null (H_o) and alternative (H_a) hypotheses to be tested are described below:

Are regenerative air street sweepers effective at reducing the stormwater load from metals associated with a particle size less than fine sand?

H_o: For PM <250μm diameter, the median quarterly average load picked up by the sweeper (mg/curb mile) is greater than or equal to the target removal load (60 percent of the median available quarterly average street dirt load).

H_a: For PM <250μm diameter, the median quarterly average load picked up by the sweeper (mg per curb mile) is less than the target removal load (60 percent of the median available quarterly average street dirt load).

If the null hypothesis (H_o) is true, then average conditions indicate there is potential for street sweeping to reduce the street dirt load at a level of treatment similar to stormwater structural BMPs, for PM <250μm diameter.

Are regenerative air street sweepers effective at removing the bulk of the stormwater metals loading?

H_o: For all PM, the median quarterly average load picked up by the sweeper (mg per curb mile) is greater than or equal to the target removal load (60 percent of the median available quarterly average street dirt load).

H_a: For all PM, the median quarterly average load picked up by the sweeper (mg per curb mile) is less than the target removal load (60 percent of the median available quarterly average street dirt load).

If the null hypothesis (H_o) is true, then average conditions indicate there is potential for street sweeping to reduce the street dirt load delivered to the receiving environment at a level of treatment similar to stormwater structural BMPs.

The supporting assumptions used include:

A particle size less than fine sand (250 μm diameter) is representative of the typical monitored pollutant load removed by structural treatment BMPs. Although Ecology (2008) previously defined total suspended solids as all particles smaller than 500 microns in diameter when applying treatment performance goals, monitoring data from automatic samplers have been reported to be less reliable at capturing PM greater than 250 μm (Clark et al 2007).

A target removal load of 60 percent of the median available quarterly average street dirt load represents the equivalent structural stormwater BMP removal efficiency for typical Seattle TSS data and Ecology performance standards for basic treatment. See section 4.2 for derivation.

Street dirt represents the average potential pollutant load to be removed by street sweeping as quantified under the pilot study monitoring protocols; quarterly composites of samples for each catchment collected approximately once every four weeks on one to two days before sweeping from the side of the street scheduled for sweeping. The available street dirt load does not include the street dirt permanently stored in the street surface cracks and crevices that is not available for washoff or sweeper pickup or load buildup or washoff between sweeping events that do not coincide with sampling events. See 0 for plots of the data.

Catch basin sediment represents the cumulative load washed off the street and captured in the catch basin as quantified under the pilot study monitoring protocols; quarterly composites of samples for each catchment collected once every four weeks from each catch basin.

Sweeper waste represents the load removed by street sweeping under the pilot study operating conditions (regenerative air sweeper operating at 4 to 6 miles per hour sweeping every other week with parking compliance) and monitoring protocols; quarterly composites of samples for each catchment collected once every four weeks from each dumpster.

2.3.3 Changes from the QAPP

The tentatively proposed paired data statistical test (t-statistic or Wilcoxon signed rank one-sample test) described in the QAPP was replaced with a nonparametric test for independent data sets (Wilcoxon rank sum). This is believed to be a reasonable change for two reasons:

(1) The data collected during the pilot study do not clearly meet the criteria for a paired test, e.g. a direct relationship between each specific data point in the sweeper waste data set does not have one and only one specific data point in the street dirt set. Although the street dirt and sweeper waste samples were collected at a

similar frequency, they were not collected at the same time or over the same accumulation period. For example, street dirt samples represent the amount accumulated on one side of the street over a two-week period before sweeping while the sweeper waste samples represent the total amount swept on a weekly basis from alternate sides of the street, and the street dirt samples were collected between 1 week before and 2 weeks after the sweeper waste samples were collected. In addition, the catch basin sediment volume were also measured once every 4 weeks, but samples for mass and pollutant concentration were collected quarterly and represented all material accumulated since the beginning of the study.

(2) Given the small data set, the generally accepted assumption that environmental data is typically lognormally distributed, and that a non-parametric test will have less power than a parametric test, this approach is considered conservative.

2.3.4 MANAGEMENT ACTIONS

Stormwater managers in the Puget Sound region may consider the effectiveness of regenerative air street sweeping to remove fine particles when determining the appropriate mix of structural stormwater BMPs and regenerative air street sweeping to optimize water quality benefits in a cost-effective manner.

2.3.5 TEMPORAL SCALE

Street dirt, catch basin sediment, and sweeper waste samples were collected over a one-year study period, from the third quarter of 2006 through the second quarter of 2007 (Table 4). The study was conducted during the permit cycle but the results may be used to inform the stormwater management program over the next several decades.

Table 4. Sampling periods (see Pilot Study, Table 6).

Material Type	Sampling Schedule	West Seattle	Southeast	Duwamish Diagonal
Street Dirt	Frequency	Every 4 weeks	Every 4 weeks	Every 4 weeks
	First sample collection day	7/18/2006	7/17/2006	12/07/2006
	Sampling period end	6/11/2007	07/02/2007	06/14/2007
Street Sweeping	Frequency	Every 2 weeks	Every 2 weeks	Every 2 weeks
	Sampling period start	6/6/2006	6/6/2006	11/10/2006
	First day of sweeping	6/20/2006	6/20/2006	11/24/2006
	Sampling period ends	6/19/2007	6/19/2007	6/15/2007
	Sampling period (days)	378	378	217
Catch Basins	Frequency	Every 4 weeks	Every 4 weeks	Every 4 weeks
	Sampling period start	6/16/2006	6/16/2006	11/16/2006
	Sampling period end	6/11/2007	6/19/2007	07/06/2007
	Sampling period (days)	360	368	232

3 Sample Collection Methodology

This section describes the sampling collection and analysis as well as evaluation methodology.

3.1 Pilot Study Sample Collection

The pilot study samples were collected from June 6, 2006, through June 19, 2007 at two residential test sites (West Seattle and Southeast Seattle), and from November 7, 2006 through July 6, 2007 at the Duwamish Diagonal industrial test site. Please refer to the Pilot Study report (SPU and Herrera 2009) for additional information on sample collection procedures.

Catch basin sediment were sampled at 12 catch basins in each site, representing most of the catch basins in the swept and unswept sites in the West Seattle study area (16 and 18 total catch basins, respectively) and the Duwamish Diagonal study area (16 and 17 total catch basins, respectively), and representing approximately one-third of the catch basins in the swept and unswept sites in the Southeast Seattle study area (38 and 36 total catch basins, respectively).

The catch basins were cleaned prior to sampling. Sediment accumulation was measured and samples were collected once every 4 weeks from both swept and unswept sites for 12 monitoring events in the two residential study areas and for 9 monitoring events in the Duwamish Diagonal study area.

Catch basin sediment and debris samples were collected to the maximum depth possible using a stainless steel scoop attached to an extension pole. Given the small amount of sediment accumulation (1 to 2 inches over the study period), it was not feasible to sample only the material that accumulated between sampling dates. Therefore, the sample represented the sediment that accumulated over the entire study period rather than the sediment accumulated between each sampling event. Between three and 20 scoops (depending upon the volume recovered) of sediment were collected from within each catch basin, emptied into a large stainless steel bowl, and homogenized using a stainless steel spoon. Particles greater than approximately 2 centimeters (cm) in size (which were rare) were removed from the sample, placed in a separate container, and weighed to determine the proportion of debris. Leaves and leaf particles were not removed from the samples. Free standing liquid was decanted from the scoop and the mixing bowl prior to sample homogenization. A pint jar was then filled with the homogenized material.

Street dirt samples were collected and weighed once every four weeks from both the swept (before sweeping) and unswept sites. Sample collection was scheduled to occur one or two days before sweeping. Samples were collected from alternate sides of the street on each consecutive sampling event to coincide with street sweeping events. When street dirt sampling was delayed due to weather, the field crew sampled the side of the street that was scheduled to be swept the following day. Individual samples were then composited prior to weighing and archiving for chemical analysis.

Samples were collected using a hand-operated industrial vacuum cleaner (Shop-Vac™). A stainless steel spatula and tongs were used when necessary to dislodge compacted material, particularly along the curb line. The Shop-Vac™ was equipped with a 2.5 horsepower motor that creates 90 inches of sealed suction pressure and can move 100 cubic feet per minute of air. The Shop-Vac™ was equipped with teflon vacuum tubing, a stainless steel hopper, and a 14-inch wide by 0.5-inch deep aluminum nozzle.

Sweeper waste (see Figure 5 for typical makeup) samples were collected once every 4 weeks or more often when necessary from material collected and stored in separate dumpsters assigned to each test site. Grab samples were collected from multiple locations in the dumpster using a stainless steel shovel. Individual grabs were placed in a stainless steel mixing bowl and particles greater than 2 cm in diameter were removed by hand and weighed separately to determine the proportion of debris in the waste material. The remaining material was homogenized using a stainless steel spoon, transferred into two or three 16-ounce jars, and stored until the end of the 12- or 16-week sampling period. One 16-ounce jar was refrigerated at 4ºC for physical analyses and one or two jars, (depending upon the organic matter content of the sample), were frozen at -18ºC for chemical analyses.

Figure 5. Sweeper waste on July 11, 2006.

3.2 Sample Analysis for S8.E

Archived, frozen excess sample volume for each of the 33 samples collected during the pilot study, using the procedures described above and listed in Table 5, were analyzed by the analytical laboratory:

- Used Method ASTM D422 to determine the particle size distribution (percent retained by weight) for the following sieve sizes: >75 mm , 50 - 75 mm, 38 - 50 mm, 25.4 - 38 mm, 19 - 25.4 mm, 12.7 - 19 mm, 9.5 - 12.7 mm, 4.75 - 9.5 mm, 2 - 4.75 mm, 850 µm - 2 mm, 425 - 850µm, 250 - 425µm, 150 – 250 µm, 75 – 150 µm, <75 µm.

- Composited the sieved fractions into four Wentworth classes: gravel (>2000 µm), coarse to medium sand (250-to-2000 µm), fine sand (75 -to-250 µm), and silt and clay (<75 µm).

- Analyzed each of the four Wentworth classes for metals (arsenic, cadmium, chromium, copper, lead, silver, zinc).

Table 5. Original composite sample collection scheme at swept sites.

Land Use	Location [a]	Source [b]	No. of Samples	Composite 1 Sample Date 2006-Q3	Composite 2 Sample Date 2006-Q4	Composite 3 Sample Date 2007-Q1	Composite 4 Sample Date 2007-Q2
Industrial	DDE	CB	3	Not sampled	01/30/2007	04/10/2007	07/09/2007
	DDE	SD	3	Not sampled	01/30/2007	04/10/2007	06/22/2007
	DDE	SW	3	Not sampled	01/30/2007	04/11/2007	06/20/2007
Residential	CCS	CB	4	10/16/2006	01/17/2007	04/10/2007	06/20/2007
	CCS	SD	4	10/17/2006	01/17/2007	04/10/2007	07/02/2007
	CCS	SW	4	10/17/2006	01/17/2007	04/11/2007	06/20/2007
	WSN	CB	4	10/16/2006	01/17/2007	04/10/2007	06/20/2007
	WSN	SD	4	10/17/2006	01/17/2007	04/10/2007	06/22/2007
	WSN	SW	4	10/17/2006	01/17/2007	04/11/2007	06/20/2007
Total			**33**				

[a] Diagonal Duwamish East (DDE), Columbia City South (CCS) in Southeast Seattle, and West Seattle North (WSN).
[b] Catch basin sediment (CB), street dirt (SD), and sweeper waste (SW).

3.3 Quality Assurance Review Summary

A quality assurance review of the field samples was completed by Herrera Environmental Consultants, Inc. and is incorporated as Appendix B in the Seattle Street Sweeping Pilot Study Monitoring Report (SPU and Herrera 2009) and summarized in this section. A quality assurance review of the laboratory quality control data was completed by SPU for this evaluation and included a review and assessment of:

- Analytical method
- Holding time
- Specified method reporting limits
- Laboratory quality control (QC) samples analyzed at correct frequency and with acceptable limits
- Correct units and significant figures
- Transcription error checking.

Analytical results were received for 33 particle size distributions and 29 metal results (Table 6). There was not adequate sample volume to analyze metal concentrations for four of the 4th quarter composite samples (street dirt and sweeper waste from Southeast Seattle and West Seattle).

Table 6. Archive sample analysis scheme.

Land Use	Location[a]	Source[b]	No. of Samples PSD/Metal [c]	Composite 1 Sample Date 2006-Q3	Composite 2 Sample Date 2006-Q4	Composite 3 Sample Date 2007-Q1	Composite 4 Sample Date 2007-Q2
Industrial	DDE	CB	3/3	Not sampled	01/30/2007	04/10/2007	07/09/2007
	DDE	SD	3/3	Not sampled	01/30/2007	04/10/2007	06/22/2007
	DDE	SW	3/3	Not sampled	01/30/2007	04/11/2007	06/20/2007
Residential	CCS	CB	4/4	10/16/2006	01/17/2007	04/10/2007	06/20/2007
	CCS	SD	4/3	10/17/2006	Inadequate sample volume for metals	04/10/2007	07/02/2007
	CCS	SW	4/3	10/17/2006	Inadequate sample volume for metals	04/11/2007	06/20/2007
	WSN	CB	4/4	10/16/2006	01/17/2007	04/10/2007	06/20/2007

Land Use	Location[a]	Source[b]	No. of Samples PSD/Metal [c]	Composite 1 Sample Date 2006-Q3	Composite 2 Sample Date 2006-Q4	Composite 3 Sample Date 2007-Q1	Composite 4 Sample Date 2007-Q2
	WSN	SD	4/3	10/17/2006	Inadequate sample volume for metals	04/10/2007	06/22/2007
	WSN	SW	4/3	10/17/2006	Inadequate sample volume for metals	04/10/2007	06/20/2007
Total			**33/29**				

[a] Diagonal Duwamish East (DDE), Columbia City South (CCS) in Southeast Seattle, and West Seattle North (WSN).
[b] Catch basin sediment (CB), street dirt (SD), and sweeper waste (SW).
[c] Particle size distribution (PSD for 15 sieve sizes) and total recoverable metals (arsenic, cadmium, chromium, copper, lead, silver, and zinc in four composited sieve fractions.

The inadequate sample volume for metals analysis of all four sieve fractions in the four samples is likely attributable to the nature of these samples. After further review of the original (non-archived) PSD results, four PSD samples received a QC flag of questionable (Q); two street dirt samples collected during the fourth quarter of 2006 (Composite 2) due to a change in street dirt sampling methods and two sweeper waste samples collected in the same quarter which likely were influenced by snow and ice sanding operations (Table 7).

Table 7. Original (non-archived) PSD samples that are questionable.

Basin	Sweep Status	Matrix	Sample ID	Analysis Date	Dg (µm)	σg	Percent <250 µm	QC Flag	QC Reason
Southeast Seattle	Swept	Street Dirt	CCS-SD-COMP	01/17/2007	1,900	4.3	4.8	Q	Suspected outlier due to first attempt to remove dirt from cracks and shaking of dirt from plant material.
Southeast Seattle	Swept	Sweeper Waste	CCS-SW-COMP	01/17/2007	1,360	4.4	9.9	Q	Potential influence of sanding from snow removal operations.
West Seattle	Swept	Sweeper Waste	WSN-SW-Comp	01/17/2007	2,860	6.0	6.3	Q	Potential influence of sanding from snow removal operations.
West Seattle	Unswept	Street Dirt	WSS-SD-COMP	01/17/2007	1,050	4.2	14.9	Q	Suspected outlier due to first attempt to remove dirt from cracks and shaking of dirt from plant material.

Table 8 includes the batches of data received from ARI (Analytical Resources Incorporated) in May/June 2008. The samples analyzed in these batches were collected in 2006/2007.

Table 8. Sample batch identification, methods, and sample number analyzed.

Results and method	Size fraction	Sample Batch ID	No. Samples	Analysis Date
Grain size ASTM D422	for all archived samples	ml65	33	04/09/2008
Total metals (As, Cd, Cr, Cu, Pb, Ag, Zn), ICP, SW6010B	Silt/clay fraction	mu64	20	05/14/2008
		mu65	9	05/15/2008
	fine sand	mu66	20	05/15 and 05/16/2008
		mu67	9	05/17 and 05/19/2008
	coarse medium sand	mu68	20	05/17/2008
		mu69	9	05/17/2008
	gravel	mu70	20	05/17 and 05/19/2008
		mu71	9	05/17/2008

Holding times The holding times for metals analysis, two years for samples frozen at -18°C, were met. The holding time for grain size analysis, six months for refrigerated samples, was not met. Samples were analyzed 9 to18 months after collection. These samples were qualified with a J flag.

Method Reporting Limits Table 9 lists the method reporting limits that did not meet the specified criterion and the qualifying flags applied.

Table 9. Method reporting limits (MRLs) for archived samples that did not meet the criterion specified in the QAPP.

Sample Batch	Parameter	Units	Specified MRL	Reported MRL	Quality Flag	Notes
All	Arsenic	mg/kg	5	10	J	Applied "J" to all affected samples (reported as <10) because the reported MRL≤ 2 times specified MRL.
	Silver	mg/kg	0.3	0.7 or 0.8	R	Applied "J-" to all affected samples (reported as <0.7 or 0.8) because the reported MRL is >2 times the specified MRL.
MU66 through MU71	Cadmium	mg/kg	0.2	0.5	R	Applied "J-" to all affected samples (reported as <0.5) because the reported MRL is >2 times the specified MRL.

Chromium, copper, lead, and zinc results are all detected above the method reporting limit (MRL). Silver, arsenic, and cadmium are detected 14, 18, and 81 percent of the time, respectively. Table 10 summarizes the detection results.

Table 10. Percent detection for reported archive sample metal sample results.

Land Use	Location	Source	No. of Samples	As	Cd	Cr	Cu	Pb	Ag	Zn
Industrial	DDE	CB	12	0%	100%	100%	100%	100%	33%	100%
	DDE	SD	12	0%	92%	100%	100%	100%	25%	100%
	DDE	SW	12	0%	83%	100%	100%	100%	25%	100%
Residential	CCS	CB	16	50%	81%	100%	100%	100%	0%	100%
	CCS	SD	12	50%	75%	100%	100%	100%	8%	100%
	CCS	SW	12	33%	58%	100%	100%	100%	8%	100%
	WSN	CB	16	6%	100%	100%	100%	100%	12%	100%
	WSN	SD	12	17%	67%	100%	100%	100%	8%	100%
	WSN	SW	12	0%	67%	100%	100%	100%	8%	100%
Total			**116**	**18%**	**81%**	**100%**	**100%**	**100%**	**14%**	**100%**

Laboratory QC Table 11 lists the laboratory QC samples that did not meet the criteria stated in the QAPP and the resulting qualifying flag. QAPP criteria include 75 to 120 percent recovery of matrix spikes and laboratory control standards, and less than or equal to 25 percent RPD for laboratory duplicates. Method blanks met the criterion.

Table 11. Laboratory QC samples that did not meet the archived sample analysis criteria.

Sample Batch No.	Qualifying notes
MU64	Cr matrix spike low (72%), so J applied to all results. Cu and Zn matrix spike concentrations over calibration curve high standard so invalid but no qualifier necessary.
MU65	No matrix spike, no duplicate, so applied spike and duplicate qualifiers from MU64 (Cr results qualified with J). Ag lab control standard low (73%). J applied to Ag results.
MU66	Cu matrix spike low (37%), so J applied to all Cu results. Zn matrix spike concentration over calibration curve high standard so invalid.
MU67	No matrix spike, no duplicate.
MU68	Zn matrix spike concentration over calibration curve high standard so invalid but no qualifier necessary.

Sample Batch No.	Qualifying notes
MU69	No matrix spike, no duplicate.
MU70	Cr, Cu, Pb duplicate RPDs too high (52, 26, 36%) so J applied to these results.
MU71	No matrix spike, no duplicate.

Comparison of original with archived particle size distribution During the QAPP review process Ecology raised a concern over the potential for the freeze/thaw cycle to modify the original sample PSD by the creation of additional fines. When comparing the original PSD for each sample to the archived PSD (Table 12), there is a slight (5 percent) loss of fines on average for the portion less than 250 µm (RPDs ranging from -18 percent to +19 percent). This is considered to be within the normal range of sample precision and the archived sample analyses are not substantially biased for more or less fines than the original sample analyses performed within the maximum holding time.

Table 12. Relative percent difference comparison of the cumulative percent passing 250**µm** of original and archived sample composites to assess impact of freeze/thaw cycle on the amount of fines.

Land Use	Location	Source	No. of Samples	Original Sample Composite Average	Archived Sample Composite Average	Relative Percent Difference
Industrial	DDE	SD	3	56	52	-6%
	DDE	CB	3	51	47	-8%
	DDE	SW	3	43	36	-18%
Residential	CCS	SD	4	30	36	19%
	CCS	CB	4	40	36	-11%
	CCS	SW	4	22	23	5%
	WSN	SD	4	44	42	-5%
	WSN	CB	4	55	51	-8%
	WSN	SW	4	26	24	-7%
Overall Average				41	39	-5%

However, there are larger variances in the individual sample relative percent differences (Table 13). Five relative percent differences exceeded the criterion of 25 percent on an individual sample basis. Of those five, three lost fines (-29, -26, and -33 percent) and two gained fines (+48 and +70 percent), indicating that one freeze/thaw cycle did not likely significantly impact the archived samples PSD.

Table 13. Relative percent difference comparison of the cumulative percent passing 250 **µm** of original and archived samples to assess impact of freeze/thaw cycle on fine generation by year (yy) and sample quarter.

Land Use	Location	Source	n	Original Samples Sample Quarter				Archived Samples Sampling Quarter				Percent Difference			
				06-Q3	06-Q4	07-Q1	07-Q2	06-Q3	06-Q4	07-Q1	07-Q2	06-Q3	06-Q4	07-Q1	07-Q2
Industrial	DDE	SD	3		46	58	62		42	57	58		-9%	-3%	-7%
	DDE	CB	3		53	63	37		48	57	37		-1	-10%	%
	DDE	SW	3		47	38	45		35	31	42		-29%	-18%	-8%

Land Use	Location	Source	n	Original Samples Sample Quarter				Archived Samples Sampling Quarter				Percent Difference			
				06-Q3	06-Q4	07-Q1	07-Q2	06-Q3	06-Q4	07-Q1	07-Q2	06-Q3	06-Q4	07-Q1	07-Q2
Residential	CCS	SD	4	54	4.8	25	35	61	5.9	41	36	13%	21%	48%	2%
	CCS	CB	4	37	35	36	51	36	30	34	42	-2%	-14%	-5%	-20%
	CCS	SW	4	32	9.9	8.7	36	29	7.6	18	37	-11%	-26%	70%	2%
	WSN	SD	4	59	23	47	47	57	20	46	45	-5%	-14%	-2%	-3%
	WSN	CB	4	62	45	53	61	50	52	48	53	-20%	15%	-10%	-15%
	WSN	SW	4	36	6.3	27	36	33	4.5	25	35	-9%	-33%	-6%	-3%

Pink = qualified sample
Red = RPD that exceeds criterion of 25%.

4 Evaluation Methodology

This section describes the methodology used to evaluate the data presented in the Results Section.

Considerations on use of the data The street dirt, sweeper waste, and catch basin samples are composites in space and time that are generally representative of the test site, but were not collected from the exact same area and had not accumulated over the exact same period. Catch basin sediment samples represent cumulative composites for the quarter, with some loss expected due to washout. Composite samples are adequate for estimating the population medians, but do limit the information related to extreme values, both large and small. In addition, composites in time will likely mask any temporal trends.

Error may have been introduced during freezing and reanalyzing.

Comparing street dirt and sweeper waste PM for each particle size fraction requires a common basis. In this case, kg per curb mile is used as the common basis. This introduces additional uncertainty into the analysis because street dirt characteristics (load and solids size distribution) vary over the course of the year, and are influenced by road condition, precipitation and other factors.

Metal concentration sample results that are detected in less than 85 percent of the samples are not included in the analysis. This includes arsenic, cadmium, and silver, which were detected 12, 19, and 14 percent of samples, respectively.

Catch basin and street dirt copper concentrations are likely low due to interference.

Presentation of the data Box plots are used to illustrate the range, central tendency, and distribution of the data. The boxes represent the interquartile range (25th and 75th percentile values); the median value is shown as the line between the gray and blue portion of the box, the mean as a "+", outside values (more than 1.5 times the interquartile range but no more than 3 times the interquartile range above the upper quartile, and those values that are more than 1.5 times the interquartile range but no more than 3 times the interquartile range below the lower quartile) as "*", and far outside values (at least 3 times the interquartile range above the upper quartile or 3 times the interquartile range below the lower quartile) as "o".

4.1 Estimating Quarterly Average Metal Loads on a Curb Mile Basis

Estimating the quarterly average metal loads on a curb mile basis is a three-step process:

- Step 1 – the quarterly average loading rates are estimated (kg material available as street dirt and picked up as sweeper waste per curb mile).
- Step 2 – the quarterly average PM load available as street dirt and picked up as sweeper waste are estimated for each size fraction (kg PM per curb mile).
- Step 3 – the quarterly average metal load available in street dirt and picked up as sweeper waste are estimated for each size fraction for chromium, copper, lead, and zinc.

4.1.1 Step 1 – Estimate quarterly Average Loading Rate (kg material per curb mile)

Sweeper Waste pick up rate – The quarterly average sweeper waste pickup rate is estimated by dividing the total dry weight removed by the sweeper during the quarter by the total miles swept during the quarter.

Street Dirt loading rate - The quarterly average street dirt loading rate is estimated by adjusting the measured load by the estimated residual load, where the measured quarterly average street dirt load is a weighted average and estimated by summing the products of the number of sweeping events for each sample by the measured load and dividing by the number of sweeping events for the quarter. If the street dirt loading rate is greater than the sweeper waste pickup rate for that quarter, the street dirt loading rate is set to the sweeper waste pickup rate.

The available street dirt load is a result of deposition and removal rates, from washoff and sweeping, plus "permanent storage" (Pitt et al 2004). The residual load, or permanent storage, is not removed by either wind, washoff, nor sweeping and is a function street texture and condition; the street dirt is trapped in the cracks and crevices (Pitt et al 2004). Figure 6 illustrates the conceptual deposition and removal process from street sweeping. In reality, deposition does not occur at the steady rate shown due to gains and losses associated with rain, wind, and other factors that act upon the non-permanent fraction of street dirt between sweeping events.

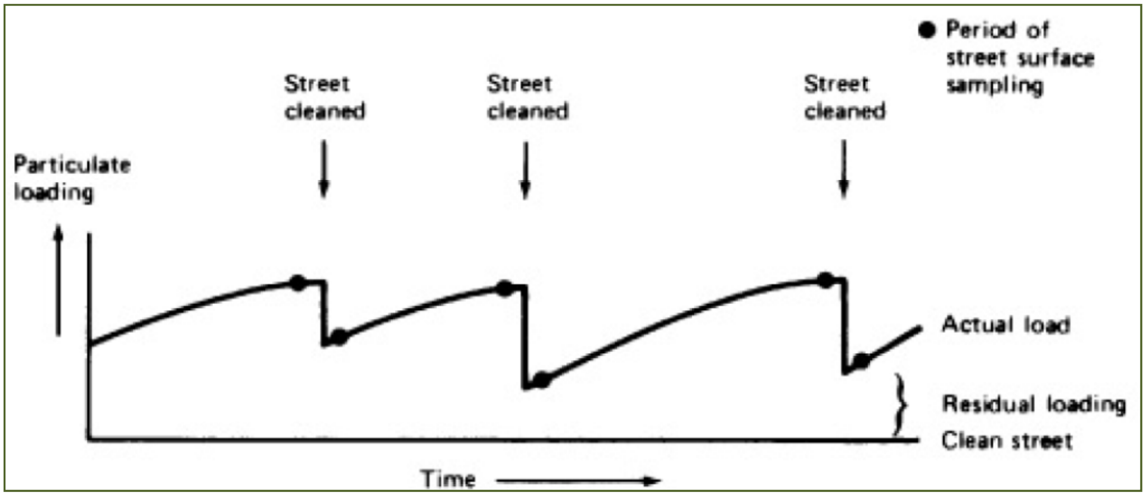

Figure 6. Sawtooth pattern associated with the deposition and removal of particulates (from Pitt, 1979).

The method to estimate the residual load is based on a visual review of the street dirt plots (see Appendix A) to determine a likely value. As a preliminary approach, we used 25 percent of the 5th percentile loading rate (kg material per curb mile). Values of 13, 8, and 14 kg per curb mile are used for Diagonal Duwamish, Southeast Seattle, and West Seattle, respectively. 0 presents the data graphically.

Table 14 provides the estimated street dirt loading (kg SD per curb mile) and sweeper waste removed (kg SW per curb mile) used to adjust the basis for comparing street dirt PM to sweeper waste PM. This data is derived from the Pilot Study (see tables 7 and 10, SPU and Herrera 2009).

Table 14. Selected loading rates for street dirt and removal rates for sweeper waste (kg material per curb mile).

Basin	Period	Number of Events during the Quarter			Quarterly Average Loading Rate (kg material per curb mile swept)		
		Sweeping	Street Dirt Sampling	Sweeper Waste Sampling	Measured Street Dirt	Estimated Street Dirt for Hypothesis Testing	Sweeper Waste Removed
Diagonal Duwamish	2006-Q4	5	3	3	290	370	370
	2007-Q1	11	3	3	100	100	99
	2007-Q2	13	3	3	200	190	41
Southeast Seattle	2006-Q3	15	4	4	150	140	120
	2006-Q4	12	2	5	36	110	110
	2007-Q1	11	3	3	96	88	70
	2007-Q2	13	3	3	42	62	62
West	2006-Q3	15	4	4	190	180	69

Basin	Period	Number of Events during the Quarter			Quarterly Average Loading Rate (kg material per curb mile swept)		
		Sweeping	Street Dirt Sampling	Sweeper Waste Sampling	Measured Street Dirt	Estimated Street Dirt for Hypothesis Testing	Sweeper Waste Removed
Seattle	2006-Q4	11	2	4	110	92	64
	2007-Q1	11	3	3	220	210	100
	2007-Q2	13	3	3	63	56	55

Measured quarterly average street dirt load is a weighted average and estimated by summing the products of the number of sweeping events for each sample by load and dividing by the number of sweeping events.
Estimated quarterly average street dirt load for hypothesis testing is the measured load adjusted by the estimated residual load and/or adjusted so that street sweeping does not remove more load than was available.
Quarterly average sweeper waste load removed is a weighted average and estimated by dividing the total dry weight of material removed for the quarter by the total number of miles swept.

Table 15 provides a comparison of the street dirt loads with national values. Seattle unswept streets median load ranges from 360 to 550 kg per curb-mile, slightly heavier loads than the unswept residential streets of Madison Wisconsin (210 to 305 kg per curb mile) but comparable to those reported for Bellevue, Washington (370 kg per curb mile). Seattle swept streets mean load ranges from 100 to 180 kg per curb mile, which compares well with Champaign, Illinois, San Jose, California, and the nation (185, 141, and 178 kg per curb mile, respectively).

Table 15. Comparison of street dirt loads to those for other residential streets (kg per curb mile)

Source	Sweeping Status	Basin/Location	Median	Mean
Seattle Pilot Study	Swept	Diagonal Duwamish	158	177
		Southeast Seattle	67	103
		West Seattle	105	157
	Unswept	Diagonal Duwamish	360	381
		Southeast Seattle	460	566
		West Seattle	552	583
Madison, Wisconsin (Selbig, 2007)	Unswept	Control	259	279
		Air Sweeper	305	353
		High-frequency broom	207	254
		Low-frequency broom	222	221
Other Residential Areas (Selbig, 2007)	Not specified	Champaign, Ill [1]		185
		Bellevue, WA [2]	320	370
		San Jose, CA [3]		141
		U.S nationwide [4]		178

Original source:
[1] Bender and Terstriep, 1984.
[2] Pitt, 1985.
[3] Pitt, 1979
[4] Sartor and Boyd, 1972.

4.1.2 Step 2 – Estimate PM Load per curb Mile

Street Dirt PM Load (PML_{sd}) – Street Dirt PM load available per curb mile for each size class (kg SD PM per curb mile) is equal to the percent of PM in the size fraction (kg PM/100 kg material) times the street dirt loading rate (kg material per curb mile).

$$PML_{sd}\left(\frac{SD\ kg_{\ pm}}{curb\ mile}\right) = \frac{SD\ kg_{\ pm}}{100\ kg\ SD_{matl}}x\frac{SD\ kg_{\ matl}}{curb\ mile}$$

Sweeper Waste PM Load (PML_{sw}) – Sweeper Waste PM load removed per curb mile for each size class (kg SW PM per curb mile) is equal to the percent of PM in the size fraction (kg PM/100 kg material) times the sweeper waste pickup rate (kg material per curb mile).

$$PML_{sw}\left(\frac{SW\ kg_{\ pm}}{curb\ mile}\right) = \frac{SW\ kg_{\ pm}}{100\ kg\ SW_{matl}}\, x\, \frac{SW\ kg_{\ matl}}{curb\ mile}$$

4.1.3 STEP 3 – ESTIMATE METAL LOAD PER CURB MILE

Street Dirt Metal Load (ML_{sd}) - Street Dirt metal load available for each size class (mg pollutant per curb mile) is equal to the PM load (kg per curb mile) times the concentration (mg/kg of PM).

$$ML_{sd}\left(\frac{mg}{curb\ mile}\right) = PML_{sd}x[SD]\left(\frac{mg}{kg_{\ pm}}\right)$$

Sweeper Waste Metal Load (ML_{sw}) – Metal load removed by sweeper for each size class (mg pollutant per curb mile) is equal to the PM load (kg per curb mile) times the concentration (mg/kg of PM).

$$ML_{sw}\left(\frac{mg}{curb\ mile}\right) = PML_{sw}x[SW]\left(\frac{mg}{kg_{\ pm}}\right)$$

4.2 Estimating the Street Sweeping Target Removal Efficiency

The target removal efficiency (RE) is the removal efficiency street sweeping would need to meet to provide a similar level of treatment under the performance standards for structural BMPs as described by the Ecology TAPE guidance (Ecology 2011). The target removal efficiency is assumed to be 60, 50, and 60 percent for total suspended solids (TSS), total copper, and total zinc, respectively based on the following:

4.2.1 STEP 1 – ESTIMATE THE TARGET REMOVAL EFFICIENCY FOR PM LOAD WITH PARTICLE DIAMETERS LESS THAN 250 µM

Removal of PM with particle diameters less than 250 µm falls under Ecology's basic treatment performance goals. For influent TSS concentrations less than 100 mg/L, facilities should achieve an effluent goal of 20 mg/L TSS. The median Seattle stormwater concentration for three land uses (n=34) is 49 mg/L TSS (SPU 2011). Therefore, assuming an influent concentration of 49 mg/L and an effluent concentration of 20 mg/L results in a removal efficiency of 59 percent (rounded up to 60 percent). For reference, the National Stormwater Quality Database median concentration of 49.8 mg/L for a sample size of 3,404 (Maestre & Pitt 2005). Thus, an influent concentration of 49 mg/L is a reasonable basis for determining the basic treatment removal efficiency target.

Under typical operating and sampling conditions, structural treatment BMPs are expected to remove 65 to 84 (CPW 2007) percent of material less than 250 µm diameter. CPW 2007 reports TSS removal efficiencies of 49, 59, 72, 80, 81, 86, and 89 percent for dry ponds, bioretention, wetlands, wet ponds, open channel, filtering practice, and infiltration respectively. The median removal efficiency for these practices is 80 percent with an interquartile range of 65 to 84 percent (CPW 2007).

The street sweeping removal efficiency (RE) for all material less than a particular size (p) is estimated by comparing the street dirt and sweeper waste PM load per curb mile for each size fraction for the quarter:

$$RE_p = \frac{PML_{sw}\left(\frac{SW\ kg_{\ pm}}{curb\ mile}\right)_p}{PML_{sd}\left(\frac{SD\ kg_{\ pm}}{curb\ mile}\right)_p}$$

4.2.2 Step 2 – Estimate the Target Removal Efficiency for Street Sweeping Metal Loads

Removal of metals falls under Ecology's enhanced treatment performance goals. Facilities should achieve 30 and 60 percent removal efficiency for dissolved copper and zinc, respectively, to meet enhanced treatment goals.

Development of metal load street sweeping target removal efficiencies is based on the assumption that Seattle stormwater median dissolved metal fraction (f_d) is approximately 0.35 and 0.36 for copper and zinc, respectively, based on a sample size of 34 for three land uses (see Table 3 from SPU 2011). Estimating the total metal target removal efficiency is a three step process:

Step 2a (FR_{pb}, particulate bound fraction removed) – estimate the fraction of total metal removed if particulate bound metal is removed at the basic treatment goal (60 percent removal of TSS).

$$FR_{pb} = (1 - f_d)x\ RE_{tss}$$

Step 2b (FR_d,dissolved fraction removed) – estimate the fraction of total metal removed if the dissolved fraction is removed at the enhanced treatment goal (30 and 60 percent removal efficiency for dissolved copper and zinc, respectively).

$$FR_d = (f_d)x\ RE_{Cu,Zn}$$

Step 2c (RE, removal efficiency for total metal) – estimate the removal efficiency for the total metal by adding the particulate bound and dissolved fractions removed.

$$RE_t = 100x\left(FR_{pb+}FR_d\right)$$

Table 16 outlines the calculation steps for copper and zinc.

Table 16. Estimation of target removal efficiencies for copper and zinc.

Calculation Steps	Copper	Zinc
Step 2a (FR_{pb}, particulate bound fraction removed)	(1-0.35) x 60 percent target removal of TSS = 0.39	(1-0.36) x 60 percent target removal of TSS = 0.38
Step 2b (FR_d,dissolved fraction removed)	0.35 x 30 percent target removal of dissolved copper = 0.105	0.36 x 60 percent target removal of dissolved zinc = 0.216
Step 2c (RE, removal efficiency for total metal)	100 x (0.39+0.105)= 50 percent removal efficiency for total copper	100 x (0.38+0.216)= 60 percent removal efficiency for total zinc

4.3 Testing Medians

The Wilcoxon rank sum test was used to the medians of the quarterly average PM load, metal load, and concentrations for street dirt and sweeper waste for each particle size class. The Wilcoxon rank sum test, a nonparametric alternative to the two-sample t-test, measures a shift in location between two independent populations with distributions identical in shape but not necessarily symmetric (Figure 7).

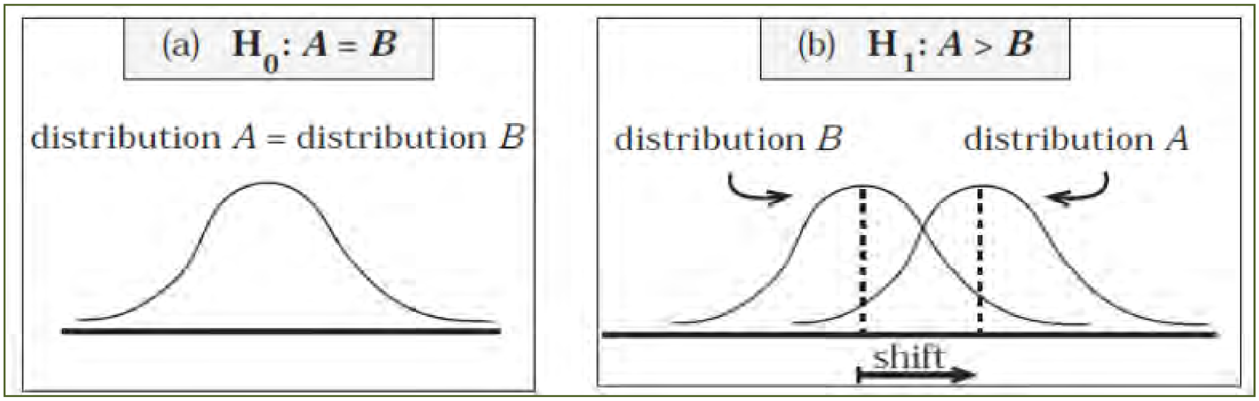

Figure 7. Illustration of the null and alternative hypothesis, testing for same median (from Wild et al 1999).

The alpha level for rejecting the null hypothesis is 0.05, which implies that the null hypothesis is rejected 5 percent of the time when it is in fact true. The p-value, the probability that you have falsely rejected the null hypothesis, is estimated from the z score after determining the test statistic.

4.3.1 Testing Median Loads Using One-Tailed Test

If the action of sweeping removes pollutants at a level of treatment similar to structural stormwater BMPs then we assume the median of the quarterly average sweeper waste PM and metal load is greater than or equal to the median of 60 percent of the quarterly average street dirt PM and metal load (see section 4.2 for estimate of target removal efficiency).

For negative test statistic z, the p-value= 1-P(z),for positive test statistic z the p-value=P(z). For p values ≤0.05, the null hypothesis was rejected, i.e., the street sweeper does not remove street dirt at a level of treatment similar to structural stormwater BMPs (60 percent).

4.3.2 Testing Median Concentrations Using Two-Tailed Test

If the action of sweeping does not preferentially concentrate or dilute pollutants within a particle size class or wash off or wind do not preferentially concentrate or dilute street dirt pollutants within a particle size class, then the median street dirt concentration for that size class should be the same as the median sweeper waste concentration. The null hypothesis for this test is that the medians of the two groups are the same. For p values ≤0.05, the null hypothesis was rejected, i.e., the group medians are not the same.

4.4 Characterizing the Measured Load Distribution

The metal measured load distribution within each size fraction, without accounting for loading or pickup rates (per curb mile), is estimated by calculating the metal load in each size class and dividing by the total measured load.

4.4.1 Estimate the Metal Load within each Size Fraction (mg per kg material)

The metal load, L_p (mg per kg material), for each size class (p) is equal to the percent of PM in the size fraction (kg PM/100 kg material) times the metal concentration (mg per kg) for that size fraction.

$$L_p\left(\frac{mg}{kg\ material}\right) = \frac{kg_{\ pm}}{100\ kg_{matl}}\, x \left[\frac{mg_{\ metal}}{kg_{pm}}\right]$$

4.4.2 Estimate the Load Distribution (L_p (percent))

The portion of the load for each size class, L_p (%), is estimated by dividing the measured load (L_p in mg/kg material) for particle class size p by the sum of the loads for all size classes.

$$L_{p(\%)}=\frac{L_p}{\sum_{p=1}^{4} L_p}$$

4.5 Characterizing the PSD

4.5.1 Estimating the Median and Geometric Mean Particle Size

The D50 (median particle size), D16, and D84 were linearly interpolated from the cumulative distribution curves to represent the particle diameter for which 50, 16, and 84 percent of the sediment dry weight is coarser or finer than the respective mean diameter.

The geometric mean diameter dg is defined as:

$$d_{g=\sqrt{d_{16} x d_{84}}}$$

If the distribution is lognormal, d50 is equal to the geometric mean of the distribution.

5 Results

The results section includes evaluation of:

- **Particle size distribution** - This section presents the results of the PSD analysis and includes: testing median quarterly average PM loads (kg per curb mile) picked up by the sweeper against the target removal load, comparing removal efficiencies estimated for each quarter, characterizing the PSD, and comparing the PM distribution by land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste).

- **Metal concentrations** - This section presents the results of the chromium, copper, lead, and zinc metal concentrations analysis and includes: testing quarterly average street dirt and sweeper waste concentrations for the same median, comparing concentrations by land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste), and comparing concentrations with literature values.

- **Metal loads** - This section presents the results of the chromium, copper, lead, and zinc metal loads analysis and includes: testing median quarterly average metal loads (mg per curb mile) picked up by the sweeper against the target removal load and comparing the measured metal load (mg/kg material) distribution by size class and land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste).

A synopsis of the key relevant findings is discussed below.

Evaluation of the distribution of pollutants in four particle size classes (silt/clay, fine sand, coarse to medium sand, and gravel) from three sources (catch basin sediment, street dirt, and sweeper waste) indicate that regenerative air street sweeping has the potential to provide equivalent treatment and therefore equal protection to the beneficial uses of a receiving environment when compared to structural stormwater BMPs.

Regenerative air street sweeping technology implemented under the conditions described in the pilot study compares well with typical structural BMPs:

- For fines <250 µm, the median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.12, 0.21, 0.23, and 0.073, respectively), inferring that regenerative air street sweeping technology has the potential to provide treatment at a level similar to structural BMPs by reducing the stormwater chromium, copper, lead, and zinc load by 60 percent for particle diameters less than fine sand.

- For all particle size classes combined, the median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.20, 0.09, 0.41, and 0.23, respectively), inferring that regenerative air street sweeping technology has the potential to provide a level of treatment similar to structural BMPs by reducing the overall stormwater chromium, copper, lead, and zinc load by 60 percent.

Table 17 summarizes the results of the Wilcoxon rank sum test for PM, concentrations, and metal loads for PM diameters greater than and less than 250 µm.

Table 17. Wilcoxon rank sum test results comparing available street dirt to sweeper waste for PM, concentration, and load for two summary size classes.

Parameter	**Ho: Median Sweeper Waste and Street Dirt concentration (mg/kg PM) are not significantly different**		**Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt load (per curb mile)**		
	<250 µm	**>250 µm**	**<250 µm**	**>250 µm**	**All**
Particulate Matter (kg)	NA	NA	SW≥0.6SD (p=0.21)	SW≥0.6SD (p=0.95)	SW≥0.6SD (p=0.38)
Chromium (mg)	**SD>SW** (p=0.003)	**SD>SW** (p=0.027)	SW≥0.6SD (p=0.12)	SW≥0.6SD (p=0.85)	SW≥0.6SD (p=0.20)
Copper (mg)	True (p=0.14)	True (p=0.27)	SW≥0.6SD (p=0.31)	SW≥0.6SD (p=0.91)	SW≥0.6SD (p=0.09)
Lead (mg)	True (p=0.44)	True (p=0.61)	SW≥0.6SD (p=0.23)	SW≥0.6SD (p=0.88)	SW≥0.6SD (p=0.41)
Zinc (mg)	**SD>SW** (p=0.016)	True (p=0.68)	SW≥0.6SD (p=0.073)	SW≥0.6SD (p=0.82)	SW≥0.6SD (p=0.23)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, two-tailed applied to concentrations and one-tailed test applied to loads.
True – indicates the medians of the two groups are not significantly different and therefore drawn from the same population.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.
PM – particulate matter for given size class (kg)
See tables below for medians, interquartile ranges, and sample sizes.

Table 18 summarizes the results of the hypothesis testing for four size classes: silt/clay, fine sand, coarse to medium sand, and gravel. For chromium, copper, lead, and zinc, the median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) in all particle size classes except the silt/clay fraction where 60 percent of the median available quarterly average chromium and zinc street dirt load is greater than the median quarterly average sweeper waste load.

Table 18. Wilcoxon rank sum test results comparing available street dirt to sweeper waste for PM, concentration, and load for four size classes.

Metal	**Ho: Median Sweeper Waste and Street Dirt concentration (mg/kg PM) are not significantly different**				**Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt load (per curb mile)**			
	Silt/Clay (<75 µm)	**Fine Sand** (75 to 250 µm)	**Coarse Med Sand** (250 to 2,000 µm)	**Gravel** (> 2,000 µm)	**Silt/Clay** (<75 µm)	**Fine Sand** (75 to 250 µm)	**Coarse Med Sand** (250 to 2,000 µm)	**Gravel** (> 2,000 µm)
Particulate Matter (kg)	NA	NA	NA	NA	SW≥0.6SD (p=0.14)	SW≥0.6SD (p=0.25)	SW≥0.6SD (p=0.91)	SW≥0.6SD (p=0.99)
Chromium (mg)	**SD>SW** (p=0.03)	True (p=0.2)	True (p=0.14)	True (p=0.17)	**0.6SD>SW** (p=0.042)	SW≥0.6SD (p=0.18)	SW≥0.6SD (p=0.85)	SW≥0.6SD (p=0.96)
Copper (mg)	**SW>SD** (p=0.01)	True (p=0.14)	True (p=0.35)	True (p=0.57)	SW≥0.6SD (p=0.20)	SW≥0.6SD (p=0.38)	SW≥0.6SD (p=0.90)	SW≥0.6SD (p=0.91)
Lead (mg)	True (p=0.12)	True (p=0.76)	True (p=0.57)	True (p=0.38)	SW≥0.6SD (p=0.07)	SW≥0.6SD (p=0.41)	SW≥0.6SD (p=0.90)	SW≥0.6SD (p=0.91)
Zinc (mg)	**SD>SW** (p=0.047)	True (p=0.10)	True (p=0.89)	True (p=0.82)	**0.6SD>SW** (p=0.029)	SW≥0.6SD (p=0.13)	SW≥0.6SD (p=0.75)	SW≥0.6SD (p=0.97)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, two-tailed applied to concentrations and one-tailed test applied to loads.
True – indicates the medians of the two groups are not significantly different and therefore drawn from the same population.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.
PM – particulate matter for given size class (kg).
See tables below for medians, interquartile ranges, and sample sizes.

The results are presented below for particle size distribution, pollutant concentrations, and pollutant loads.

5.1 Particle Size Distribution

This section presents the results of the particle size distribution analysis and includes: testing median quarterly average PM loads (kg per curb mile) picked up by the sweeper against the target removal load, comparing removal efficiencies estimated for each quarter, characterizing the PSD, and comparing the PM distribution by land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste). Synopses of the key relevant findings are summarized below.

Results of two methods addressing the question of whether street sweeping provides equivalent removal of fine particulate matter when compared to structural treatment BMPs indicate that:

- Testing median quarterly average PM loads (kg per curb mile) for four size classes using the Wicoxon rank sum test indicated that the median load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available street dirt load) for silt and clay, fine sand, coarse to medium sand, and gravel (p-values of 0.14, 0.25, 0.91, and 0.99, respectively), inferring that regenerative air street sweeping technology has the potential to provide a level of treatment similar to structural BMPs.

- Assessing the removal efficiency of the fraction of sweeper waste less than 500 μm with paired quarterly composite street dirt samples indicates that street sweeping has the potential to provide similar removal effectiveness as structural treatment BMPs under the study conditions, with a median of 57 percent (n=9), which is near the assumed target removal efficiency of 60 percent for basic treatment.

The 95th percentiles of geometric mean (Dg) particle diameter for (710 μm, n= 10) street dirt and sweeper waste (895 μm, n= 11) are less than the minimum gravel particle diameter of 2,000 μm, and the interquartile range for street dirt (167 to 362 μm) overlaps the interquartile range for sweeper waste (342 to 438 μm), inferring that street sweeping does provide equivalent benefit when compared to structural BMPs from the perspective of capturing all particle size classes and minimizing the risk of habitat loss by increasing embeddedness.

The median geometric mean for street dirt, catch basin sediment, and sweeper waste is smaller for industrial land use (Duwamish) when compared to residential land use with the exception of West Seattle catch basin sediments in the swept basin.

Figure 8 and Figure 9 present the sample PM mass for each size class (silt/clay (<75 μm), fine sand (75 to 250 μm), coarse to medium sand (250 to 2,000 μm), and gravel (> 2,000 μm) by source (catch basin sediment, street dirt, and sweeper waste showing the distribution for archived samples and original (non-frozen) samples.

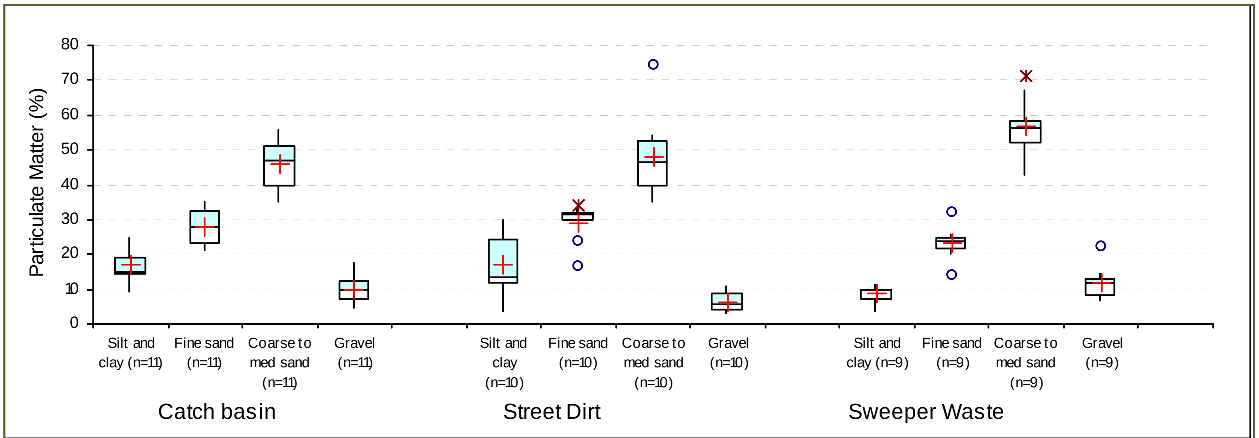

Figure 8. Box & whiskers plot of archived sample PM mass for each size class (silt/clay (<75 μm), fine sand (75 to 250 μm), coarse to medium sand (250 to 2,000 μm), and gravel (> 2,000 μm) by source (catch basin sediment, street dirt, and sweeper waste).

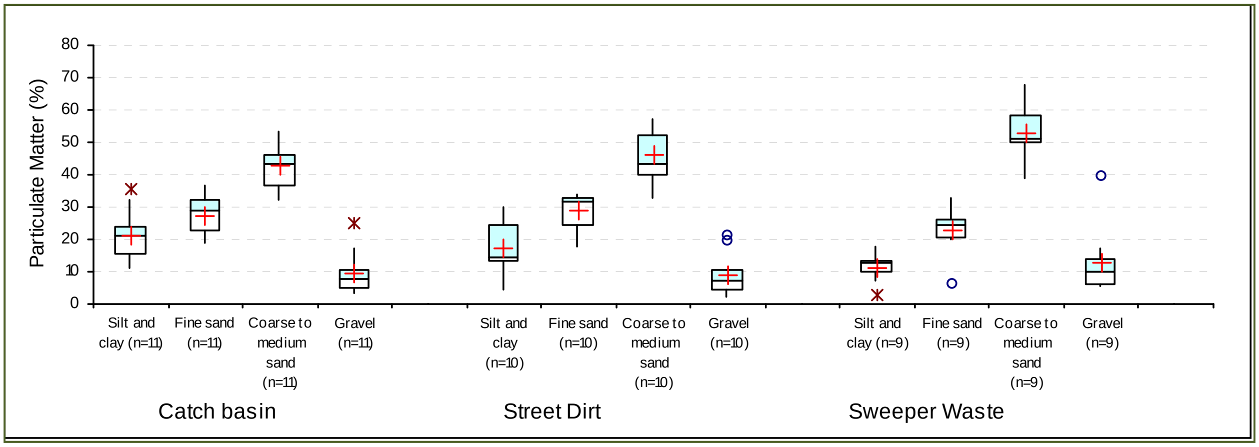

Figure 9. Box & whiskers plot of original sample PM mass for each size class (silt/clay (<75 µm), fine sand (75 to 250 µm), coarse to medium sand (250 to 2,000 µm), and gravel (> 2,000 µm) by source (catch basin sediment, street dirt, and sweeper waste).

Figure 10 and Figure 11 present the same information, but in a format intended to contrast the size fractions across the source type. From this perspective, a trend of less street sweeper PM for size classes <250 µm and greater street sweeper PM mass for size classes > 250 µm is noted. In general, for all source types (catch basin sediment, street dirt, and sweeper waste) the proportion of PM for each size class decreases in order from coarse to medium sand, fine sand, silt/clay, and gravel.

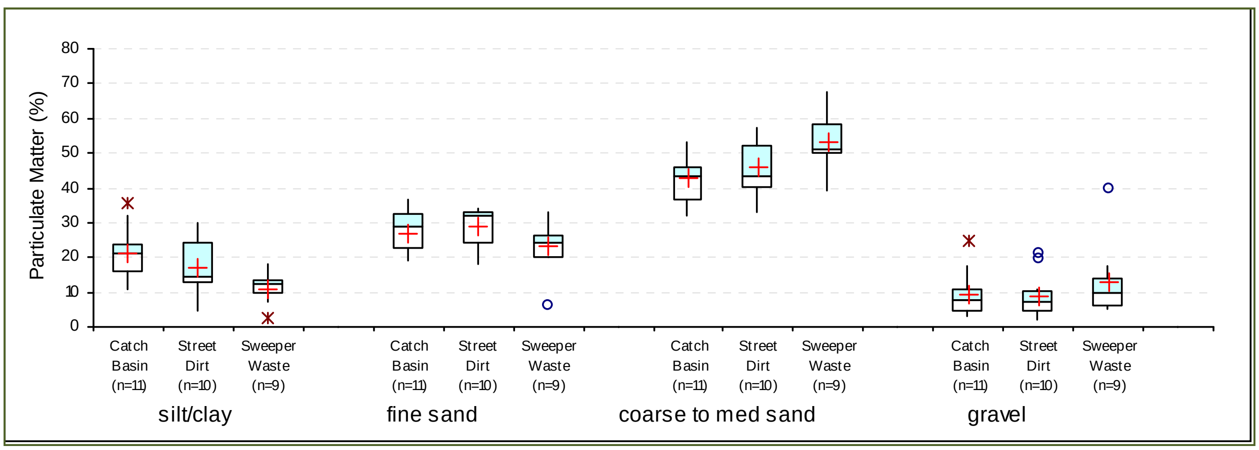

Figure 10. Box & whiskers plot of original sample PM mass for each source (catch basin sediment, street dirt, and sweeper waste) by size class (silt/clay (<75 µm), fine sand (75 to 250 µm), coarse to medium sand (250 to 2,000 µm), and gravel (> 2,000 µm).

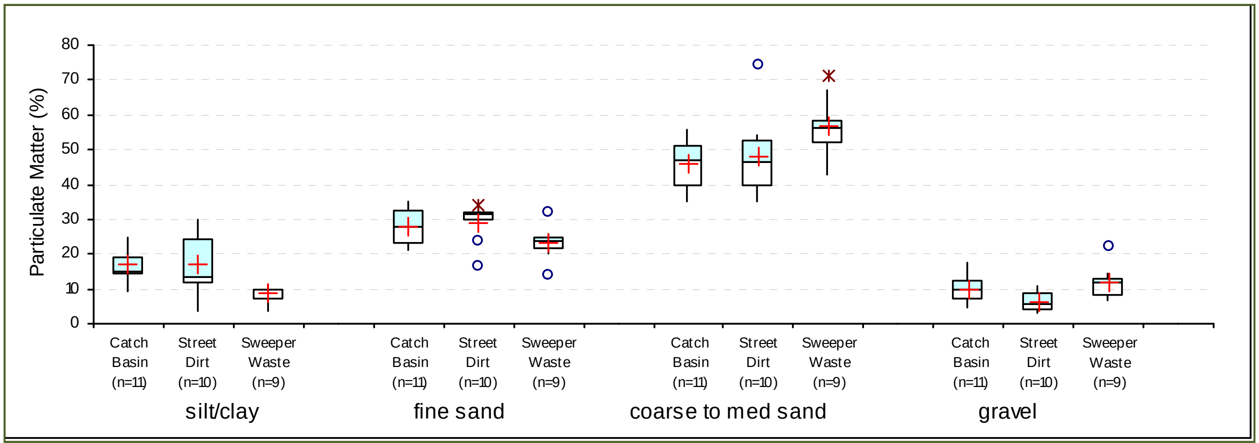

Figure 11. Box & whiskers plot of archived sample PM mass for each source (catch basin sediment, street dirt, and sweeper waste) by size class (silt/clay (<75 µm), fine sand (75 to 250 µm), coarse to medium sand (250 to 2,000 µm), and gravel (> 2,000 µm).

5.1.1 Testing Medians Against the Target

This section presents the results of testing median quarterly average PM loads (kg per curb mile) picked up by the sweeper against the target removal street dirt load.

Table 19 presents results for the Wilcoxon rank sum test comparing the sweeper waste to street dirt for source material less than 250 µm and greater than 250 µm.

Table 19. Wilcoxon rank sum test results comparing original and archived (frozen) sample PM by size class (>/<250 um for street dirt (n=10) and sweeper waste (n=9)).

Sample Status	Size Class	Median and interquartile range (IQR) (kg PM/100kg Matl)		Median and interquartile range (IQR) (kg PM/curb mile)		Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt load (per curb mile)
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	
Original	<250 µm	47 (IQR=20)	36 (IQR=5.1)	59 (IQR=81)	22 (IQR=13)	SW≥0.6SD (p=0.25)
	>250 µm	54 (IQR=20)	65 (IQR=5.5)	71 (IQR=36)	59 (IQR=26	SW≥0.6SD (p=0.89)
Archived	<250 µm	46 (IQR=15)	33 (IQR=6.3)	57 (IQR=76)	22 (IQR=13)	SW≥0.6SD (p=0.21)
	>250 µm	55 (IQR=15)	67 (IQR=6.1)	74 (IQR=45)	66 (IQR=32)	SW≥0.6SD (p=0.95)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, one-tailed test.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.
PM – particulate matter for given size class (kg).

Table 20 presents results for the Wilcoxon rank sum test comparing the samples for sweeper waste to street dirt by four size classes with similar results to a comparison using two size classes (greater and less than 250 µm).

Table 20. Wilcoxon rank sum test results comparing original and archived (frozen) sample PM mass for weeper waste to street dirt for four size classes, street dirt (n=10) and sweeper waste (n=9)).

Sample Status	Size Class	Median and interquartile range (IQR) (kg PM/100kg Matl)		Median and interquartile range (IQR) (kg PM/curb mile)		Median loads (kg PM/curb mile) of the two groups are the same
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt to Sweeper Waste
Original	Silt/Clay	15 (IQR=11)	13 (IQR=3.5)	25 (IQR=32)	6.2 (IQR=6.5)	SW≥0.6SD (p=0.23)

Sample Status	Size Class	Median and interquartile range (IQR) (kg PM/100kg Matl)		Median and interquartile range (IQR) (kg PM/curb mile)		Median loads (kg PM/curb mile) of the two groups are the same
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt to Sweeper Waste
	Fine Sand	32 (IQR=8.5)	24 (IQR=6)	34 (IQR=45	16 (IQR=7.6)	SW≥0.6SD (p=0.27)
	Coarse Med Sand	44 (IQR=12)	52 (IQR=8.4)	61 (IQR=24)	36 (IQR=27)	SW≥0.6SD (p=0.79)
	Gravel	7.1 (IQR=5.9)	9.9 (IQR=7.8)	9.7 (IQR=13)	9.8 (IQR=22)	SW≥0.6SD (p=0.90)
Archived	Silt/Clay	13 (IQR=13)	9.7 (IQR=2.6)	25 (IQR=34)	5.4 (IQR=4.6)	SW≥0.6SD (p=0.14)
	Fine Sand	31 (IQR=1.6)	24 (IQR=3.1)	32 (IQR=43)	16 (IQR=8.3)	SW≥0.6SD (p=0.25)
	Coarse Med Sand	47 (IQR=13)	56 (IQR=6.2)	67 (IQR=34)	50 (IQR=28)	SW≥0.6SD (0.91)
	Gravel	5.8 (IQR=4.4)	12 (IQR=5)	6.6 (IQR=7.8)	8.3 (IQR=14)	SW≥0.6SD (p=0.99)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, one-tailed test.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.
PM – particulate matter for given size class (kg).

5.1.2 COMPARING REMOVAL EFFICIENCIES

Although the sampling design does not support a statistical paired comparison approach, the removal efficiencies estimated from paired quarterly average composite street sweeper-street dirt results do provide additional information to support the potential for street sweeping to provide a level of treatment similar to structural BMPs. A comparison of the fraction of sweeper waste less than 500 µm and 250 µm with street dirt indicates that street sweeping approaches the Ecology performance target of 60 percent (see section 2.1.4.) removal for structural treatment BMPs for PM less than 500 µm and provided slightly less removal effectiveness for PM less than 250 µm (see Table 21):

- The Ecology basic treatment performance standard for structural treatment BMPs is an effluent goal of 20 mg/L TSS for material less than 500µm diameter for TSS concentrations less than 100 mg/L, which is approximately 60 percent for Seattle stormwater (see section 2.1.4.). The study results (for original, non-archived samples) indicated street sweeping removed 19 to 103 percent of the street dirt material available less than 500 µm diameter with a median of 57 percent (n=9), which is slightly below the assumed target removal efficiency of 60 percent.

- The study results (for non-archived samples) indicated street sweeping removed 16 to 103 percent of the street dirt material less than 250 µm diameter with a median of 52 percent (n=9), which is slightly less than the presumed target removal efficiency of 60 percent.

Table 21 presents the paired quarterly average fractions of street dirt /sweeper waste less than 500 and 250 µm diameter and the corresponding estimated removal efficiency.

Table 21. Street sweeping estimated removal efficiency for fractions less than 500 and 250 µm.

Basin	Sample Quarter	Fraction <500 µm (%)		Fraction <250 µm (%)		Street Sweeping Removal Efficiency (%)		Q Flag
		Street Dirt	Sweeper Waste	Street Dirt	Sweeper Waste	Fraction <500 µm	Fraction <250 µm	
Diagonal Duwamish	2006-Q4	70	66	46.1	47.3	94%	103%	
	2007-Q1	80	60	58.5	37.6	74%	64%	
	2007-Q2	80	70	62.2	45.1	19%	16%	

Basin	Sample Quarter	Fraction <500 µm (%)		Fraction <250 µm (%)		Street Sweeping Removal Efficiency (%)		Q Flag
		Street Dirt	Sweeper Waste	Street Dirt	Sweeper Waste	Fraction <500 µm	Fraction <250 µm	
Southeast Seattle	2006-Q3	75	50	54	32.5	57%	52%	
	2006-Q4	17	28	4.8	9.9	165%	206%	Q
	2007-Q1	48	21	25	8.7	35%	28%	
	2007-Q2	60	62	34.9	36	103%	103%	
West Seattle	2006-Q3	78	58	59.3	36.4	29%	24%	
	2006-Q4	43	18	23.2	6.3	29%	19%	Q
	2007-Q1	72	55	47	26.8	36%	27%	
	2007-Q2	68	63	46.6	35.9	91%	76%	
Median of qualified samples		**71**	**60**	**47**	**36**	**57%**	**52%**	
Median of all samples		70	58	45	40	57%	52%	
Removal efficiency estimated from PM (kg) per curb mile.								

To provide context, Table 22 shows the estimated removal efficiency comparing PM for each size fraction, assuming that the PM per curb mile is the same for street dirt and catch basins in the unswept basins. A similar trend is found in the swept basin, with the median of the qualified samples 106 (73 to 163) percent and 114 (59 to 194) percent for the fraction less than 500 and 250 µm diameter, respectively. The study results therefore indicate that the catch basins may be potentially capturing the finer material.

Table 22. Catch basin estimated PM removal efficiency in unswept basins for fractions less than 500 and 250 µm.

Basin	Sample Quarter	Fraction <500 µm (%)		Fraction <250 µm (%)		Catch Basin Removal Efficiency (%)		Q Flag
		Street Dirt	Catch Basin	Street Dirt	Catch Basin	Fraction <500 µm	Fraction <250 µm	
Diagonal Duwamish	2006-Q4	65	66	45	50	102%	111%	
	2007-Q1	84	81	62	65.5	96%	106%	
	2007-Q2	84	56	63	37	67%	59%	
Southeast Seattle	2006-Q3	72	51	50	36	71%	72%	
	2006-Q4	51	57	28	30	112%	107%	
	2007-Q1	58	61	35	37.5	105%	107%	
	2007-Q2	67	68	44	45	101%	102%	
West Seattle	2006-Q3	75	62	57	40	83%	70%	
	2006-Q4	33	62	15	36	188%	240%	Q
	2007-Q1	48	70	27	44.3	146%	164%	
	2007-Q2	72	73	52	50	101%	96%	
Median of qualified samples		**70**	**66**	**48**	**42**	**101%**	**104%**	
Median of all samples		67	62	45	40	124%	130%	

These estimated removal efficiencies compare well with the literature when considering street sweeping removal efficiencies and Seattle BMP effectiveness for a proprietary BMP treating roadway runoff.

Under two controlled condition experiments, Breault et al (2005) found vacuum type sweeper removal efficiencies ranging from less than 60 to 92 percent with ranges of 39-81 for silt and clay, 31 to 93 for fine sand, 62 to 93 for coarse sand, and 86 to 94 percent for gravel (Figure 12).

By comparison, for the nine composite samples analyzed in this study, removal efficiencies ranging from 19 to 103 percent and 16 to 103 percent for PM less than 250 µm and less than 500 µm, respectively (see Table 21).

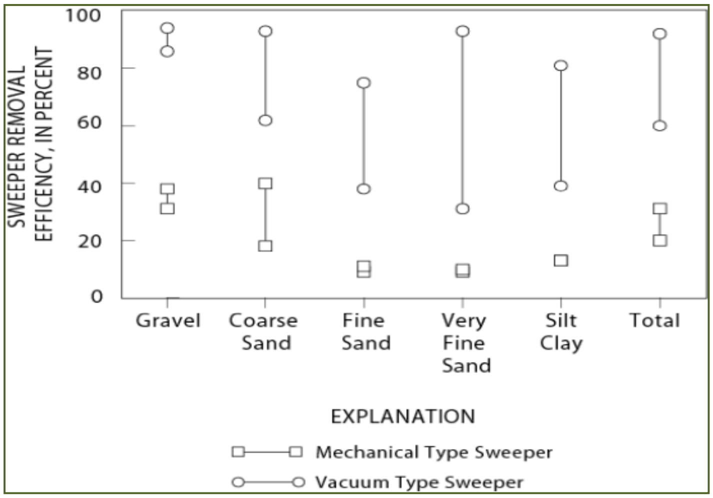

Figure 12. Street sweeper efficiencies measured for the Pelican Series P mechanical sweeper and Johnston 605 Series vacuum sweeper, New Bedford, Massachusetts (from Breault et al, 2005)

Roadway runoff data from 37 paired influent/effluent samples collected from a proprietary BMP (SPU 2011) showed 28.9 percent of the influent PM was less than 250 µm while 11.7 percent of the effluent PM less than 250 µm; therefore, this system reduced PM in this size fraction by 41 percent (Table 23). By comparison, for the nine paired composite study samples, 47 percent of the street dirt PM (comparable to the influent) was less than 250 µm. Computing the difference between street dirt and sweeper waste (comparable to the effluent) showed 11 percent (47 percent in street dirt minus 36 percent in sweeper waste) of the PM was less than 250 µm, and the median removal efficiency was 52 percent for PM in this size fraction (see Table 21).

Table 23. BMP effectiveness study results for 37 paired influent/effluent roadway runoff samples (from SPU (2011)).

Fraction	Particle Size Range (microns)	Wentworth Scale Name	Influent Distribution (% mass of total)	Effluent Distribution (% mass of total)	Mass Percent Reduction	Influent Distribution (% mass of total)	Weighted Mass Percent Reduction
< 250 µm	< 1	Colloids	5.3%	23.0%	21.2%	28.9%	41%
	1 to 3.9	Clay	6.2%	23.1%	31.6%		
	3.9 to 62.5	Silt	14.3%	43.5%	44.5%		
	62.5 to 125	Very fine sand	2.1%	4.1%	64.4%		
	125 to 250	Fine Sand	1.0%	0.4%	93.2%		
> 250 µm	250 to 500	Medium sand	10.1%	3.1%	94.3%	71.1%	98%
	> 500	Coarse sand and greater	61.0%	2.7%	99.2%		
Total							82%

5.1.3 Characterizing the Particle Size Distributions

This section includes a comparison of the cumulative PSD and describes the PSD central tendency statistic.

Comparing cumulative particle size distributions Figure 13 through Figure 15 present cumulative particle size distributions for catch basin sediment, street dirt, and sweeper waste and indicate the medians (51, 47, and 36 percent) for particles finer than 250 µm diameter for catch basin sediment, street dirt, and sweeper waste, respectively.

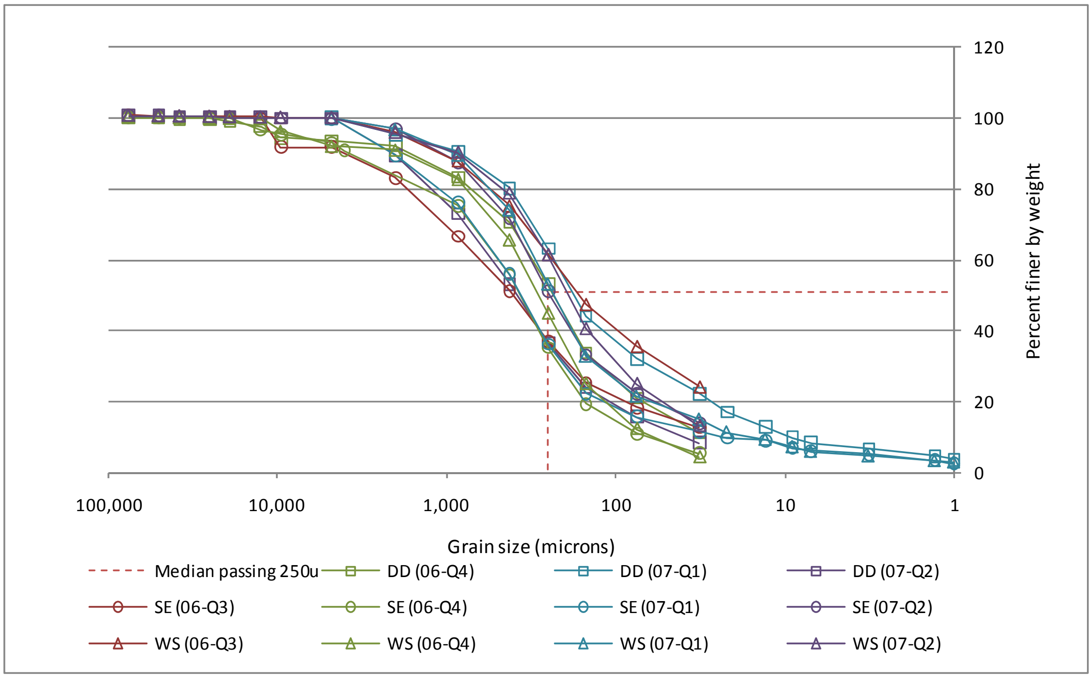

Figure 13. Cumulative particle size distribution for catch basin sediment showing median (51 percent) for percent finer than 250u (n=11).

Figure 14 presents the cumulative particle size distribution for street dirt and indicates the median percent finer by weight (47 percent) for a material less than 250 µm diameter. The one qualified sample in the swept basins (SE (06-Q4)) can be identified by the curve shape, which has significantly less fines than the other curves.

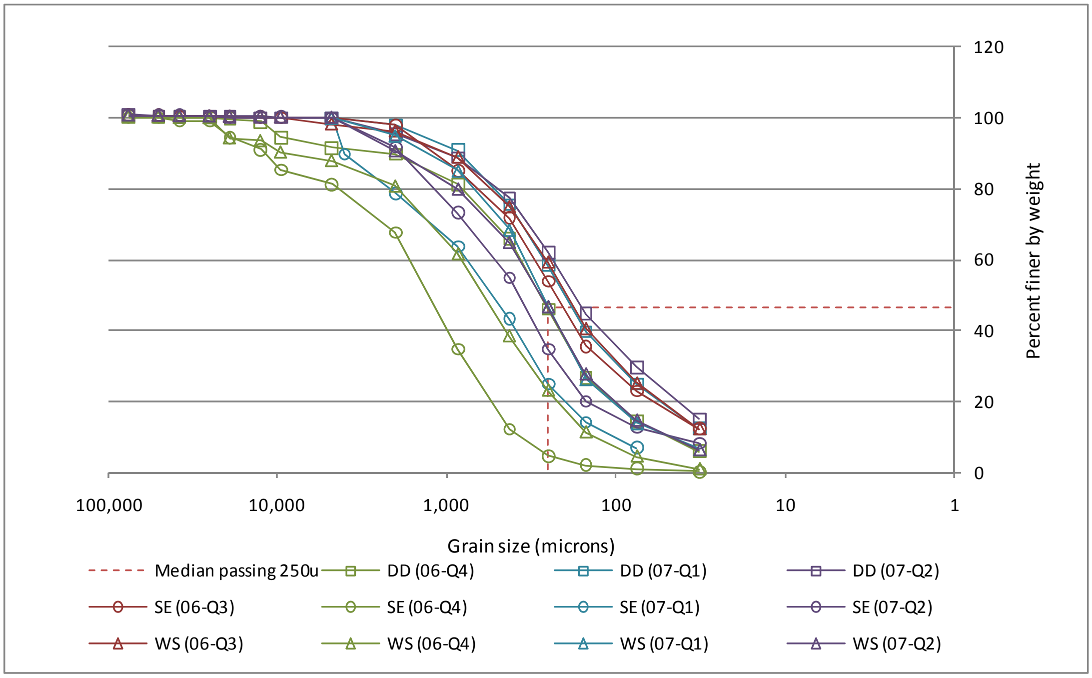

Figure 14. Cumulative particle size distribution for street dirt showing median (47 percent) for percent finer than 250u (n=10).

Figure 15 presents the cumulative particle size distribution for sweeper waste and indicates the median percent finer by weight (36 percent) for material less than 250 μm diameter. Note the shape of the two qualified samples, SE (06-Q4) and WS (06-Q4), which are suspected of being influenced by snow and ice removal operations. The sample representing the Southeast Seattle basin the first quarter of 2007 (SE (07-Q1)) may also be influenced by snow and ice removal operations or an indication of seasonal changes.

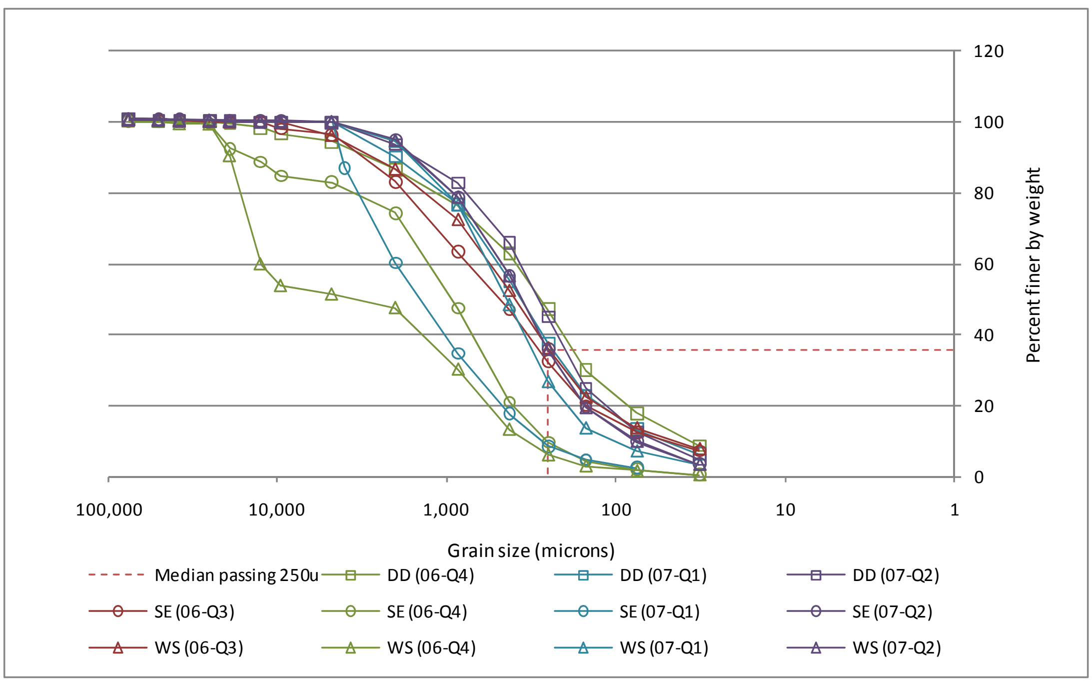

Figure 15. Cumulative particle size distribution for sweeper waste showing median (36 percent) for percent finer than 250u (n=9).

Similar to sediment suspended in the stormwater column, Seattle street dirt appears to contain relatively high percentage fines based on comparisons to data from Selbig et al 2007 and Brealt et al. 2005 that are presented in Table 24. Selbig et al (2007) measured street dirt as part of a street sweeping effectiveness study on three residential basins in Madison, Wisconsin. Brealt et al (2005) measured street dirt on two streets in New Bedford, Massachusetts.

Table 24. Comparison of median street dirt distribution (greater than/less than 250 µm) in Seattle, Madison, Wisconsin, and New Bedford, Massachusetts.

Particle Size	Madison Calibration Basin (prior to sweeping)	Madison Treatment Basin (sweeping weekly)	Madison Control Basin	New Bedford, MA	Seattle Pilot Study
< 250 µm	24	29	28	28	47
> 250 µm	76	71	72	72	54

Describing the PSD central tendency statistic. Table 25 presents the geometric mean (Dg) and median (D50) particle size for non-archived samples.

Table 25. Non-archived samples median of geometric mean (Dg) and median (D50) particle size for representative samples.

	Sample Count (n)		Geometric Mean Diameter (Dg) µm			Median Diameter (D50) µm		
	Unswept	Swept	Unswept	Swept	Combined	Unswept	Swept	Combined
Street Dirt	**10**	**10**	**258**	**281**	**271**	**270**	**270**	**270**
Duwamish	3	3	150	159	154	185	200	193
Southeast Seattle	4	3	313	382	345	343	375	375
West Seattle	3	4	235	282	261	240	270	270
Catch Basin Sediment	**11**	**11**	**313**	**210**	**247**	**343**	**240**	**265**
Duwamish	3	3	251	210	231	250	230	240
Southeast Seattle	4	4	321	328	328	365	360	360
West Seattle	4	4	305	150	197	295	210	240
Sweeper Waste		**9**		**356**	**356**		**360**	**360**
Duwamish		3		310	310		285	285
Southeast Seattle		3		458	458		480	480
West Seattle		3		380	380		390	390
All Samples Combined	**21**	**30**	**251**	**307**	**297**	**280**	**285**	**285**

Appendix B presents the relationships of Dg for qualified data.

5.1.4 Comparing PM Distribution by Size Class and Land Use (Industrial and Residential)

Figure 16 through Figure 19 present the data graphically by particle size class and site.

- **Silt/clay size class** - The industrial site (DDE) PM contains more PM in the street dirt and sweeper waste than the other sites. Residential site WSN contains more PM in the catch basin sediments.
- **Fine sand class** – Follows the silt/clay class size trend; the industrial site (DDE) PM contains more PM in the street dirt and sweeper waste than the other sites. Residential site WSN contains more PM in the catch basin sediments.

- **Coarse to medium sand class** - the residential site (CCS) contains more PM in the catchbasin sediment and street dirt than the other sites. Residential site WSN contains more PM in the sweeper waste.

- **Gravel** - The residential site (CCS) contains more PM in the street dirt, catchbasin sediment, and sweeper waste than the other sites.

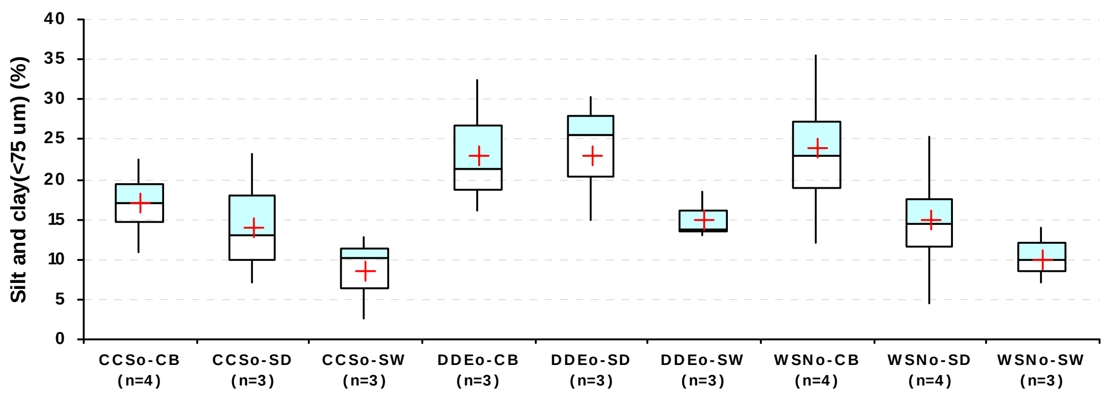

Figure 16. Box & whiskers plot for original sample silt/clay (<75 um) size class for two residential sites (CCS and WSN) and one industrial land use site (DDE).

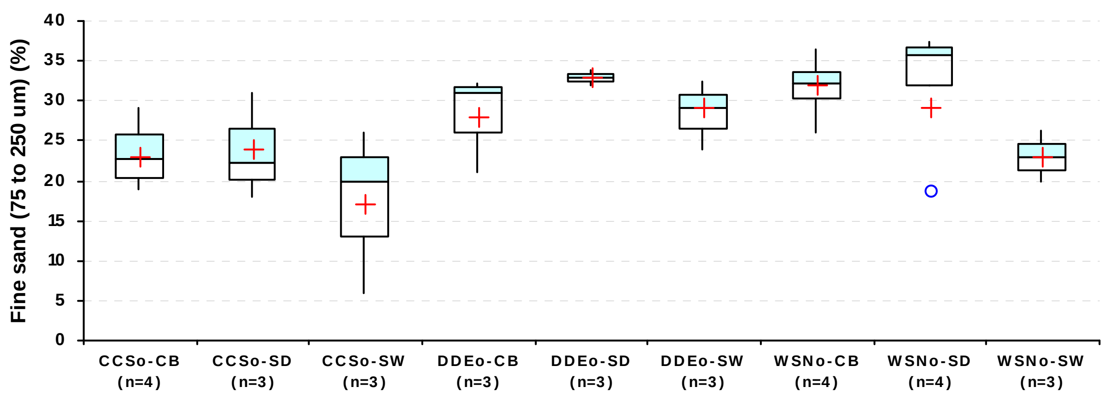

Figure 17. Box & whiskers plot for original sample fine sand (75to 250 um) size class for two residential sites (CCS and WSN) and one industrial land use site (DDE).

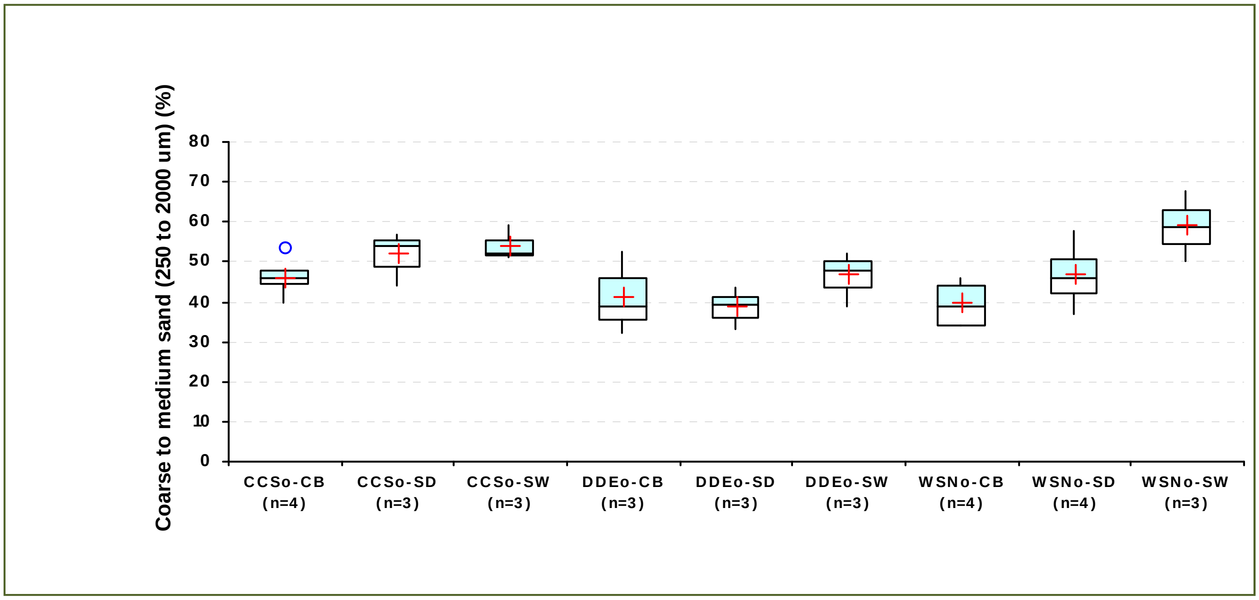

Figure 18. Box & whiskers plot for original sample coarse to medium sand (250 to 2,000 um) size class for two residential sites (CCS and WSN) and one industrial land use site (DDE).

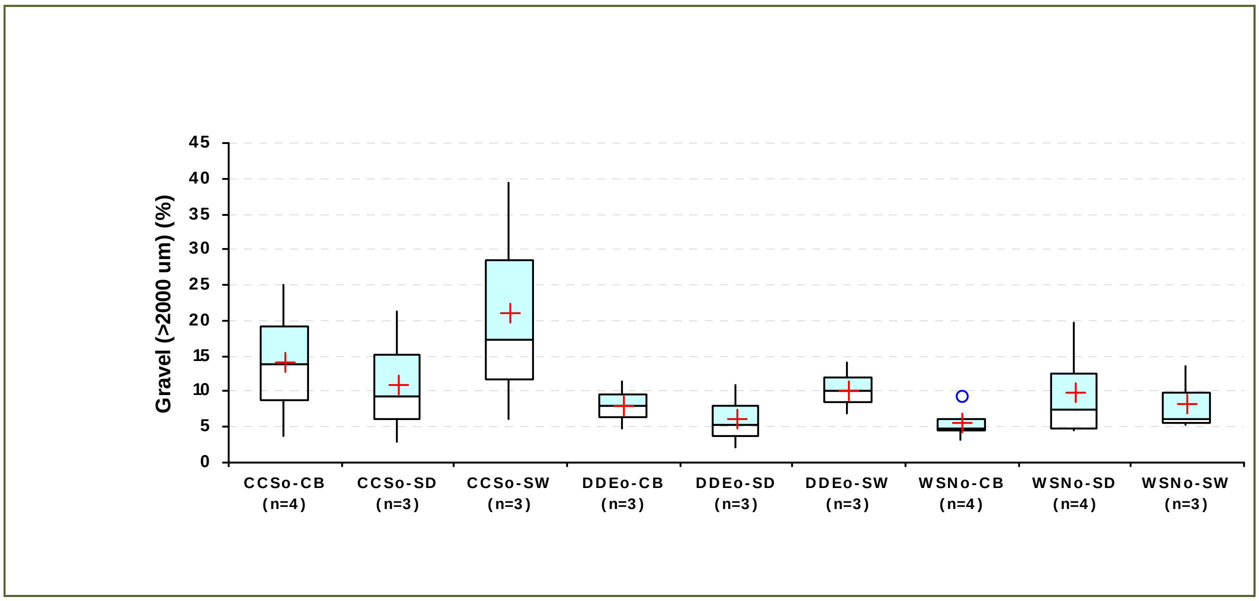

Figure 19. Box & whiskers plot for original sample gravel (> 2,000 um) size class for two residential sites (CCS and WSN) and one industrial land use site (DDE).

5.2 Metal Concentrations

This section presents the results of the chromium, copper, lead, and zinc metal concentrations analysis and includes: testing quarterly average street dirt and sweeper waste concentrations for the same median, comparing concentrations by land use, and comparing concentrations with literature values. Synopses of the key relevant findings are summarized below.

Under the study conditions, the regenerative air sweepers are shown to be effective at removing at least the same concentration available in street dirt for copper, lead, and zinc concentrations in the fine PM (< 250µm). The chromium concentrations in sweeper waste were less than those in street dirt.

For the very fine PM (silt/clay fraction) the regenerative air sweepers are shown to be effective at removing at least the same concentration available in street dirt for copper and lead. The chromium and zinc concentrations in sweeper waste were less than those in street dirt. In addition, similar results identified in the pilot study were found; zinc is a potential contaminant of concern and industrial land use contributes the highest concentrations.

This section presents the results of the pollutant concentration analysis and includes; comparing the medians and comparing the concentrations by land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste). Figure 20 through Figure 22 present copper, lead, and zinc concentrations graphically by size fraction with a general indicator level to provide an indication if the parameter may be considered a potential pollutant of concern by comparison to marine sediment quality standards. Note that this standard is not applicable to these solids but is presented here only to provide a general indication of the pollutant potential these solids.

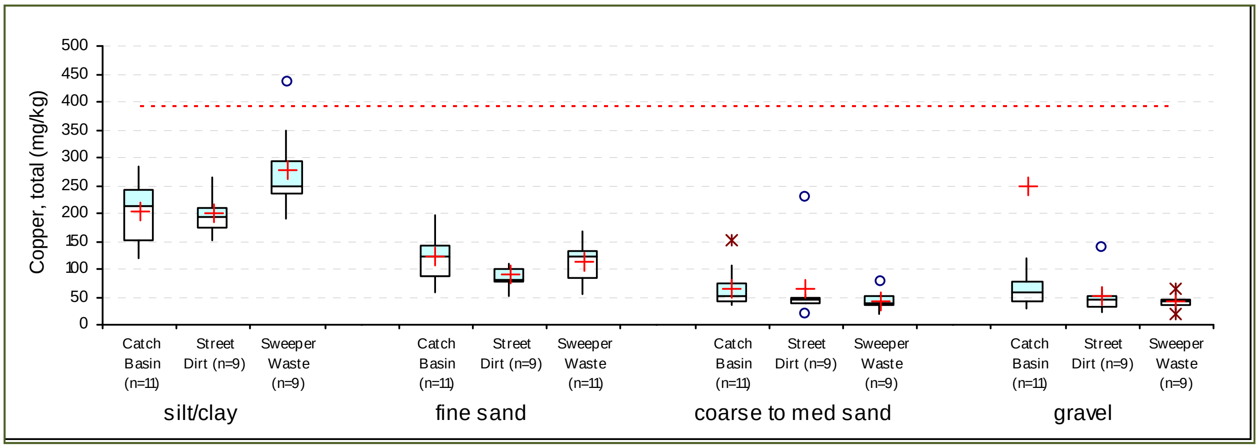

Figure 20. Box & whisker plot of copper concentrations for four size classes (silt/clay, fine sand, coarse to medium sand, and gravel) and three sources (catch basin sediment, street dirt, and sweeper waste) with indicator level (marine sediment quality standard) of 390 mg/kg.

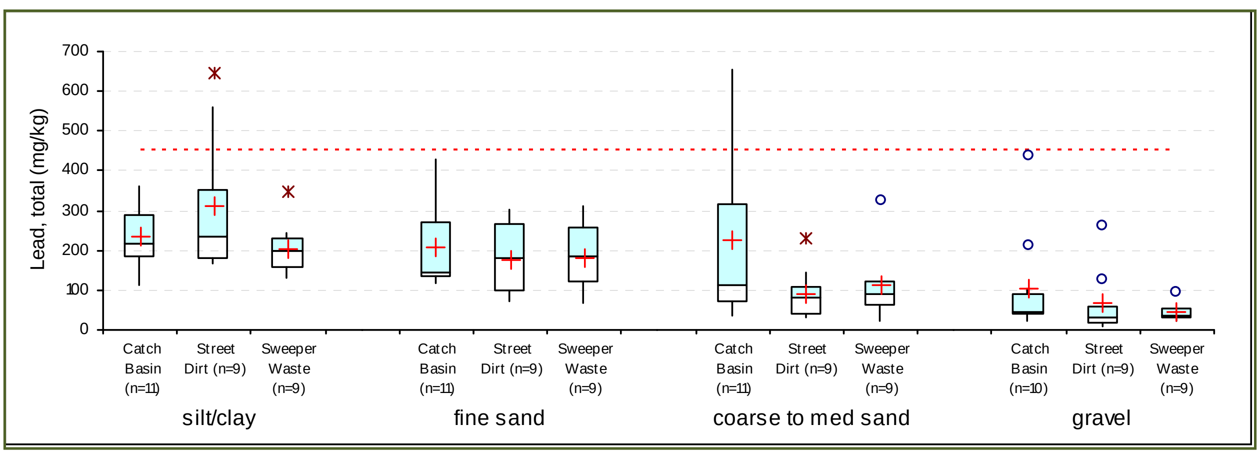

Figure 21. Box & whisker plot of lead concentrations for four size classes (silt/clay, fine sand, coarse to medium sand, and gravel) and three sources (catch basin sediment, street dirt, and sweeper waste) with indicator level (marine sediment quality standard) of 450 mg/kg.

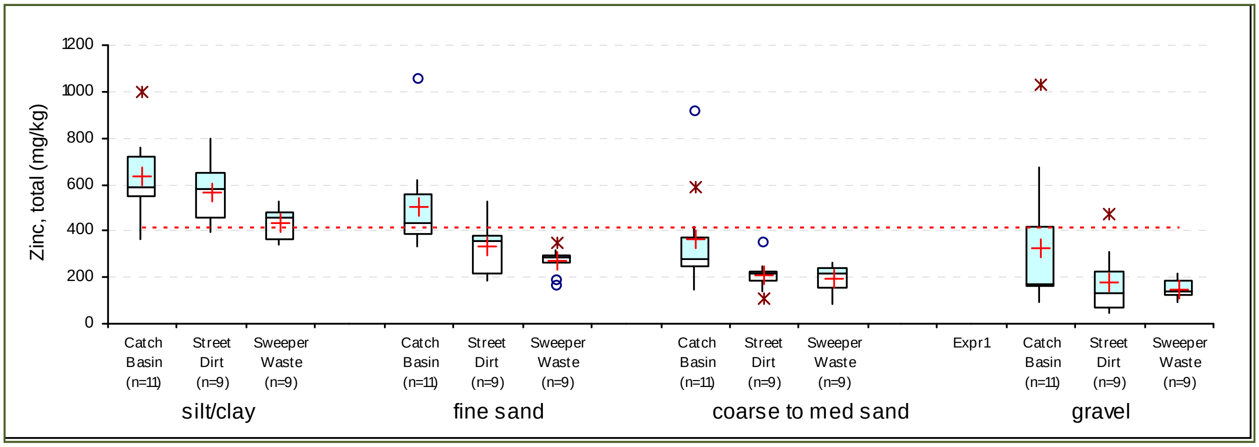

Figure 22. Box & whisker plot of zinc concentrations for four size classes (silt/clay, fine sand, coarse to medium sand, and gravel) and three sources (catch basin sediment, street dirt, and sweeper waste) with indicator level of (marine sediment quality standard) 410 mg/kg.

5.2.1 Testing Concentrations for the Same Median

Results for the Wilcoxon rank sum test comparing median concentrations for sweeper waste to street dirt indicate:

- **For PM less than 250 µm**: - The median concentrations are not significantly different (p≤0.05) for copper, lead, and zinc. There is depletion in the sweeper waste chromium and zinc (silt/clay fraction) concentrations and enrichment in the silt/clay sweeper waste copper concentration.

- **For PM greater than 250 µm**: The median concentrations are not significantly different (p≤0.05) for copper, lead, and zinc. There is depletion for chromium in sweeper waste.

Table 26 presents results for the Wilcoxon rank sum test comparing chromium, copper, lead, and zinc concentrations for sweeper waste to street dirt for PM less than 250 µm and greater than 250 µm.

Table 26. Wilcoxon rank sum test results comparing chromium, copper, lead, and zinc concentrations for sweeper waste to street dirt for PM less than 250 µm and greater than 250 µm.

PM Size	Metal	Median values (mg/kg)		Ho: Median Sweeper Waste and Street Dirt concentration (mg/kg PM) are not significantly different
		Street Dirt (SD)	Sweeper Waste (SW)	
<250 µm	Chromium	86 (IQR=28) N=18	60 (IQR=35) N=17	**SD>SW** (p=0.003)
	Copper	148 (IQR=110) N=18	180 (IQR=122) N=18	True (p=0.14)
	Lead	189 (IQR=128) N=18	187 (IQR=101) N=18	True (p=0.44)
	Zinc	421 (IQR=206) N=18	351 (IQR=157) N=18	True (p=0.096)
>250 µm	Chromium	28 (IQR=26) N=18	24 (IQR=16) N=18	**SD>SW** (p=0.027)
	Copper	46 (IQR=11) N=18	41 (IQR=13) N=18	True (p=0.27)
	Lead	56 (IQR=73) N=18	60 (IQR=60) N=17	True (p=0.61)
	Zinc	195 (IQR=101) N=18	171 (IQR=94) N=18	True (p=0.68)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, two-tailed.
True – indicates the medians of the two groups are not significantly different and therefore drawn from the same population.

Table 27 presents results for the Wilcoxon rank sum test comparing copper, lead, and zinc concentrations for sweeper waste to street dirt for four class sizes.

Table 27. Wilcoxon rank sum test results comparing copper concentrations by size class for street dirt (n=9) and sweeper waste (n=9).

Metal	Size Fraction	Median values (mg/kg)		Ho: Median Sweeper Waste and Street Dirt concentration (mg/kg PM) are not significantly different
		Street Dirt (SD)	Sweeper Waste (SW)	
Copper	Silt/Clay	194 (IQR=38)	250 (IQR=57)	**SW>SD** (p=0.01)
	Fine Sand	83 (IQR=22)	125 (IQR=47)	True (p=0.14)
	Coarse Med Sand	46 (IQR=9.5)	39 (IQR=14)	True (p=0.35)
	Gravel	46 (IQR=18)	43 (IQR=10)	True (p=0.57)
Lead	Silt/Clay	235 (IQR=174)	198 (IQR=71)	True (p=0.12)
	Fine Sand	180 (IQR=167)	184 (IQR=136)	True (p=0.76)
	Coarse Med Sand	82 (IQR=69)	92 (IQR=58)	True (p=0.57)
	Gravel	32 (IQR=41)	34 (IQR=22)	True (p=0.38)
Zinc	Silt/Clay	580 (IQR=194)	458 (IQR=111)	**SD>SW** (p=0.047)
	Fine Sand	356 (IQR=164)	289 (IQR=34)	True (p=0.096)
	Coarse Med Sand	217 (IQR=42)	216 (IQR=85)	True (p=0.89)
	Gravel	135 (IQR=161)	137 (IQR=65)	True (p=0.82)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, two-tailed.
True – indicates the medians of the two groups are not significantly different and therefore drawn from the same population

5.2.2 Comparing Metal Concentrations by Land Use (Industrial and Residential)

Metal concentrations for each source (catch basin sediment (CB), street dirt (SD), and sweeper waste (SW)) for each study test site (Columbia City South (CCS), Diagonal Duwamish East (DDE), and West Seattle North (WSN)) are presented in Appendix C.

For each parameter, the Diagonal Duwamish East study basin, which is industrial land use, generally has higher concentrations than either of the other study basins, which are both residential. The catch basin sediment concentrations from the Diagonal Duwamish East study basin are noticeably greater than the other concentrations.

5.2.3 Comparing Metal Concentrations with Literature Values

Depree (2008) compared catch basins sediment and street sweeping samples collected from three New Zealand cities that use high efficiency vacuum sweepers. His underlying assumption was that regenerative air street sweepers are effective at removing fine particulate if there is no enrichment of fine PM (<250 µm) in catch basin sediment when compared to sweeper waste. He found that:

With the exception of the 1,000 to 500 µm fraction (1.0 to 0.5 mm), there was no significant difference in particle size distribution between catch basin sediments and street sweepings (Figure 23). There was no significant difference in median total sample concentrations for the three metals considered, copper, lead, and zinc, except for zinc.

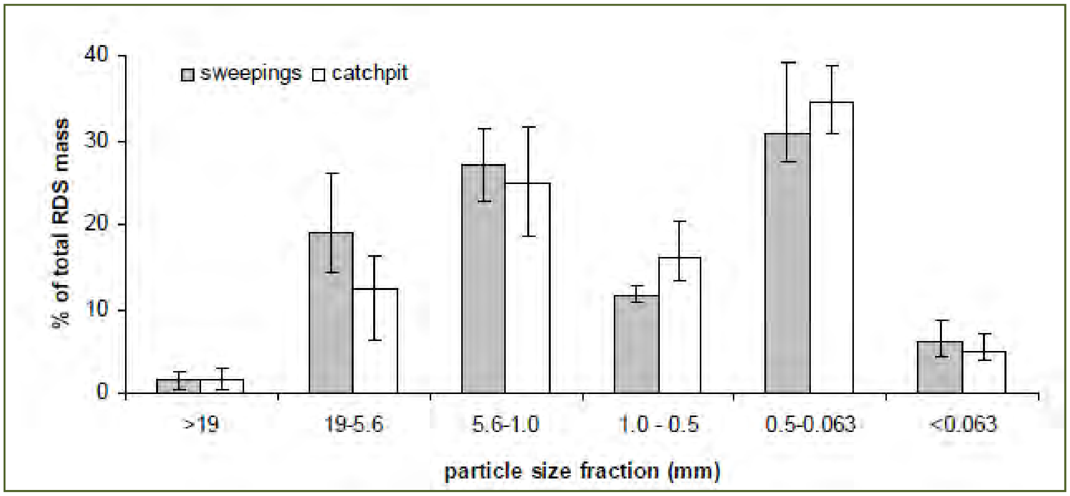

Figure 23. Median particle size distribution for street sweepings (grey bars) and catch basin sediments (white bars) from Depree (2008).[1]

The New Zealand results (Depree 2008) are similar to the Seattle pilot study results (Table 28). There was no significant difference in median total sample concentrations for the three metals considered, copper (fine sand, coarse to medium sand, and gravel size fractions), lead (silt/clay, fine sand, and coarse to medium sand size fraction), and zinc (gravel size fraction only).

Table 28. Wilcoxon rank sum test results comparing copper, lead, and zinc concentrations by size class for catch basin sediment (n=11) and sweeper waste (n=9).

Metal	Size Fraction	Median values (mg/kg)		Ho: Median Catch Basin and Sweeper Waste concentration (mg/kg PM) are not significantly different
		Catch Basin (CB)	Sweeper Waste (SW)	
Copper	Silt/Clay	213 (IQR=89)	250 (IQR=57)	**SW>CB (p=0.03)**
	Fine Sand	124 (IQR=56)	125 (IQR=47)	True (p=0.85)
	Coarse Med Sand	51 (IQR=32)	39 (IQR=14)	True (p=0.053)
	Gravel	57 (IQR=36)	43 (IQR=10)	True (p=0.088)
Lead	Silt/Clay	214 (IQR=101)	198 (IQR=71)	True (p=0.34)
	Fine Sand	145 (IQR=138)	184 (IQR=136)	True (p=0.52)
	Coarse Med Sand	114 (IQR=247)	92 (IQR=58)	True (p=0.34)
	Gravel	48 (IQR=117)	34 (IQR=22)	**CB>SW (p=0.015)**
Zinc	Silt/Clay	588 (IQR=169)	458 (IQR=111)	**CB>SW (p=0.001)**
	Fine Sand	432 (IQR=175)	289 (IQR=34)	**CB>SW (p=0.0002)**
	Coarse Med Sand	281 (IQR=121)	216 (IQR=85)	**CB>SW (p=0.007)**
	Gravel	173 (IQR=259)	137 (IQR=65)	True (p=0.087)
Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, two-tailed. True – indicates the medians of the two groups are not significantly different and therefore drawn from the same population				

[1] Error bars represent the upper and lower quartile range.

Comparing street dirt concentrations with regional and national data Table 29 provides a comparison of the street dirt study results with other regional and national data. Lead and zinc concentrations within the Seattle area appear to have decreased since the previous dataset collected in 1973.

Table 29. Comparing street dirt concentrations with other data by size class for street dirt (mg/kg).

		This Study	New Bedford, MA (Breault et al 2005)	Hamilton, NZ (Zanders 2006)	Seattle (Pitt and Amy, 1973)
Copper	Silt/Clay	194 (IQR=38)	140	181-197	~210
	Fine Sand	83 (IQR=22)	91	184-212	~80
	Coarse Med Sand	46 (IQR=9.5)	69	21-85	~60
	Gravel	46 (IQR=18)	1,510		~50
Lead	Silt/Clay	235 (IQR=174)	490	316-322	~5,000
	Fine Sand	180 (IQR=167)	420-490	251-334	~4,000
	Coarse Med Sand	82 (IQR=69)	270	36-193	~1,900
	Gravel	32 (IQR=41)	82		~900
Zinc	Silt/Clay	580 (IQR=194)	810	1695-2080	>600
	Fine Sand	356 (IQR=164)	270-320	1073-1628	>600
	Coarse Med Sand	217 (IQR=42)	230	226-507	>600
	Gravel	135 (IQR=161)	130		~400

Comparing street dirt concentrations with Seattle stormwater PM-based concentrations Table 30 compares Seattle stormwater sample copper, lead, and zinc PM-based concentrations by land use (SPU 2011). Both copper and zinc median concentrations are greater for commercial land use when compared to industrial and residential. This may be due to the nature of the industrial basin, which contains a significant portion of residential land use or higher traffic volume in the commercial basin. When compared to catch basin, street dirt, and sweeper waste median concentrations for PM less than (<250 μm), stormwater copper concentrations are similar and stormwater zinc concentrations are higher.

Table 30. Local stormwater sample copper and zinc PM-based median concentrations by land use.

Land Use	Parameter	Seattle Stormwater Sample Median	Catch Basin Median (<250 μm)	Street Dirt Median (<250 μm)	Sweeper Waste Median (<250 μm)
Residential	Copper (mg/kg)	183 (IQR=45)	156 (IQR=21) Southeast 95 (IQR=30) West Seattle	135 (IQR=16) Southeast 121 (IQR=16) West Seattle	162 (IQR=25) Southeast 116 (IQR=19) West Seattle
	Lead (mg/kg)	278 (IQR=69)	145 (IQR=11) Southeast 185 (IQR=46) West Seattle	116 (IQR=147) Southeast 135 (IQR=172) West Seattle	133 (IQR=55) Southeast 145 (IQR=34) West Seattle
	Zinc (mg/kg)	659 (IQR=140)	482 (IQR=40) Southeast 438 (IQR=96) West Seattle	378 (IQR=102) Southeast 278 (IQR=116) West Seattle	307 (IQR=85) Southeast 337 (IQR=82) West Seattle
Commercial	Copper (mg/kg)	644 (IQR=316)	ND	ND	ND
	Lead (mg/kg)	242 (IQR=62)	ND	ND	ND
	Zinc (mg/kg)	1,511 (IQR=557)	ND	ND	ND
Industrial	Copper (mg/kg)	200 (IQR=140)	203 (IQR=16)	155 (IQR=15)	175 (IQR=26)
	Lead (mg/kg)	96 (IQR=41)	362 (IQR=19)	299 (IQR=51)	270 (IQR=33)
	Zinc (mg/kg)	1,217 (IQR=518)	678 (IQR=223)	533 (IQR=108)	325 (IQR=16)

Land Use	Parameter	Seattle Stormwater Sample Median	Catch Basin Median (<250 µm)	Street Dirt Median (<250 µm)	Sweeper Waste Median (<250 µm)
All Land Uses	Copper (mg/kg)	253 (IQR=348)	161 (IQR=78)	127 (IQR=19)	157 (IQR=44)
	Lead (mg/kg)	230 (IQR=144)	168 (IQR=138)	211 (IQR=196)	182 (IQR=121)
	Zinc (mg/kg)	1,160 (IQR=751)	488 (IQR=190)	438 (IQR=205)	312 (IQR=36)

Seattle stormwater sample median dataset includes 11, 12, and 11 samples from residential, commercial, and industrial land uses, respectively.
Seattle stormwater PM-based concentration is estimated by (particulate-bound metal concentration (ug/L)/TSS concentration (mg/L)) x 10^3 ug/kg
Pilot study sample size for all land uses PM <250 µm is 11, 9, and 9 for catch basin sediment, street dirt, and sweeper waste, respectively. This includes 8 samples from the residential and 3 from the industrial land uses for catch basins and 6 from residential and 3 from industrial for street dirt and sweeper waste.
Pilot study sample size for industrial land use for PM <250 µm is 6, 6, and 6 for catch basin sediment, street dirt, and sweeper waste, respectively.
ND – no data

5.3 Metal Loads

This section presents the results of the chromium, copper, lead, and zinc metal loads analysis and includes: testing median quarterly average metal loads (mg per curb mile) picked up by the sweeper against the target removal load and comparing the measured metal load (mg/kg material) distribution by size class and land use (residential and industrial) for each source type (catch basin sediment, street dirt, and sweeper waste). Synopses of the key relevant findings are summarized below.

The study objective was to answer two questions regarding the effectiveness of street sweeping to remove metal loads from stormwater.

Are regenerative air street sweepers effective at reducing the stormwater load from metals associated with a particle size less than fine sand?

> For fines <250 µm, the median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.12, 0.21, 0.23, and 0.073, respectively), inferring that regenerative air street sweeping technology has the potential to provide treatment at a level similar to structural BMPs by reducing the stormwater chromium, copper, lead, and zinc load by 60 percent for particle diameters less than fine sand.

Are regenerative air street sweepers effective at reducing the bulk of the stormwater metals load?

> For all particle size classes combined, the median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc (p-values of 0.20, 0.09, 0.41, and 0.23, respectively), inferring that regenerative air street sweeping technology has the potential to provide a level of treatment similar to structural BMPs by reducing the overall stormwater chromium, copper, lead, and zinc load by 60 percent.

Figure 24 through Figure 26 present box and whisker plots for copper, lead, and zinc showing the distribution of the load (mg pollutant per kg source material).

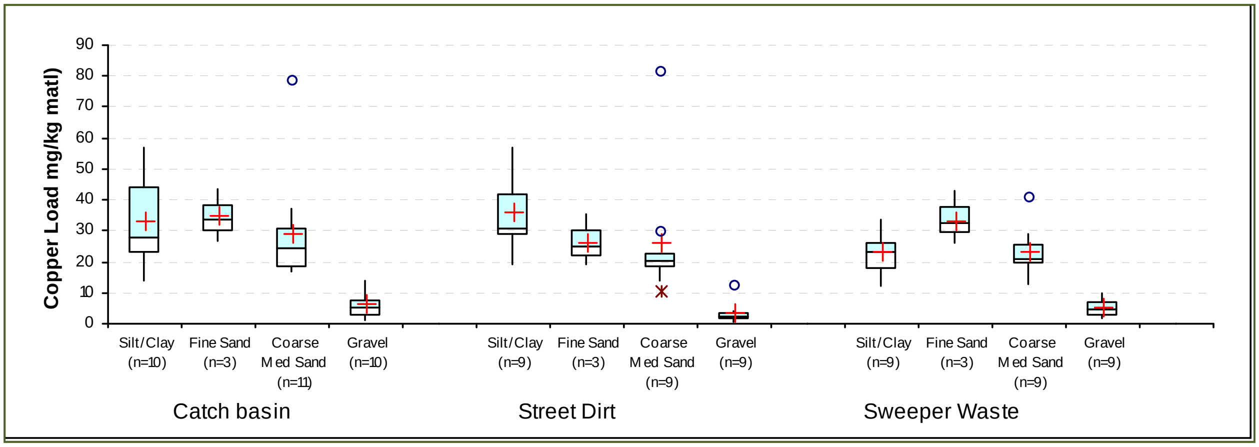

Figure 24. Box & whisker plot of copper load (mg/kg material) by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

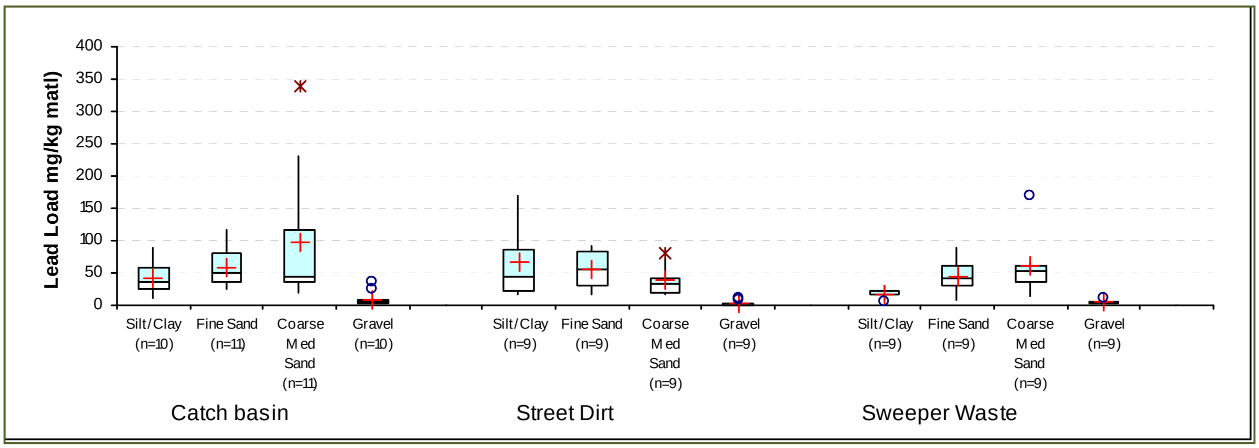

Figure 25. Box & whisker plot of lead load (mg/kg material) by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

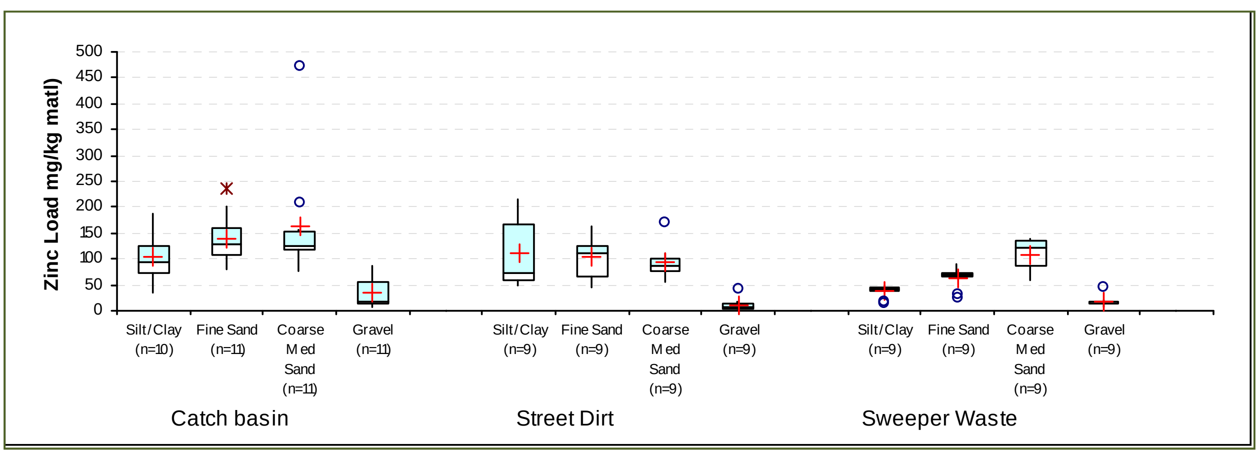

Figure 26. Box & whisker plot of zinc load (mg/kg material) by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

5.3.1 Testing Medians Against the Target

Table 31 presents results for the Wilcoxon rank sum test comparing chromium, copper, lead, and zinc loads (mg per curb mile) for PM less than 250 µm, greater than 250 µm, and for all particle diameters combined. The median quarterly average load picked up by the sweeper is significantly greater than the target removal load (60 percent of the median available quarterly average street dirt load) for chromium, copper, lead, and zinc:

- For fines <250 µm, the chromium, copper, lead, and zinc p-values are 0.12, 0.21, 0.23, and 0.073, respectively).
- For fines >250 µm, the chromium, copper, lead, and zinc p-values are 0.85, 0.91, 0.88, and 0.82, respectively.
- For all particle size classes combined, for chromium, copper, lead, and zinc p-values are of 0.20, 0.09, 0.41, and 0.23, respectively),

These results infer that regenerative air street sweeping technology has the potential to provide a level of treatment similar to structural BMPs by reducing the fines and overall stormwater chromium, copper, lead, and zinc load by 60 percent.

Figure 27 through Figure 30 summarize these results graphically.

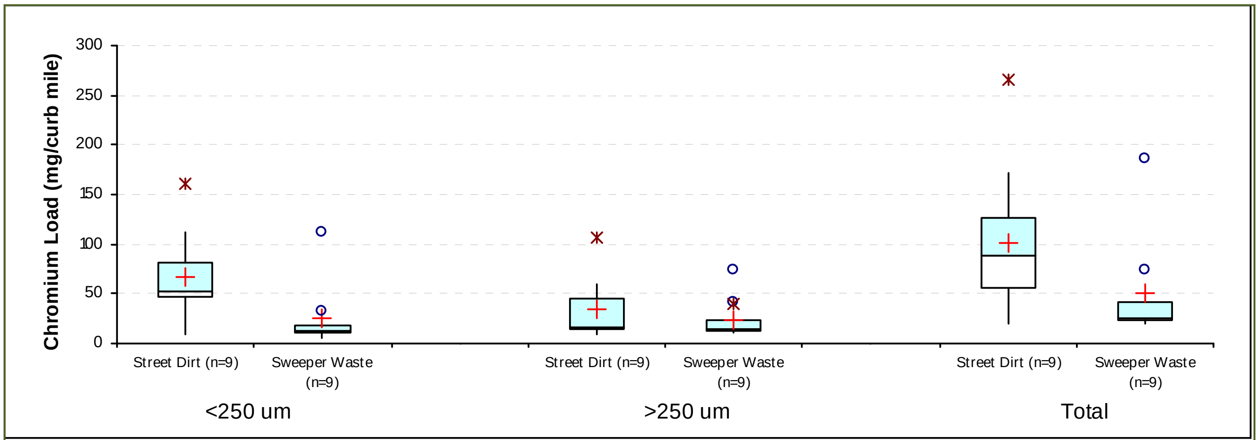

Figure 27. Box & whiskers plot comparing street dirt and sweeper waste chromium load (mg/curb mile) for PM less than 250 um, greater than 250 um, and all particle diameters.

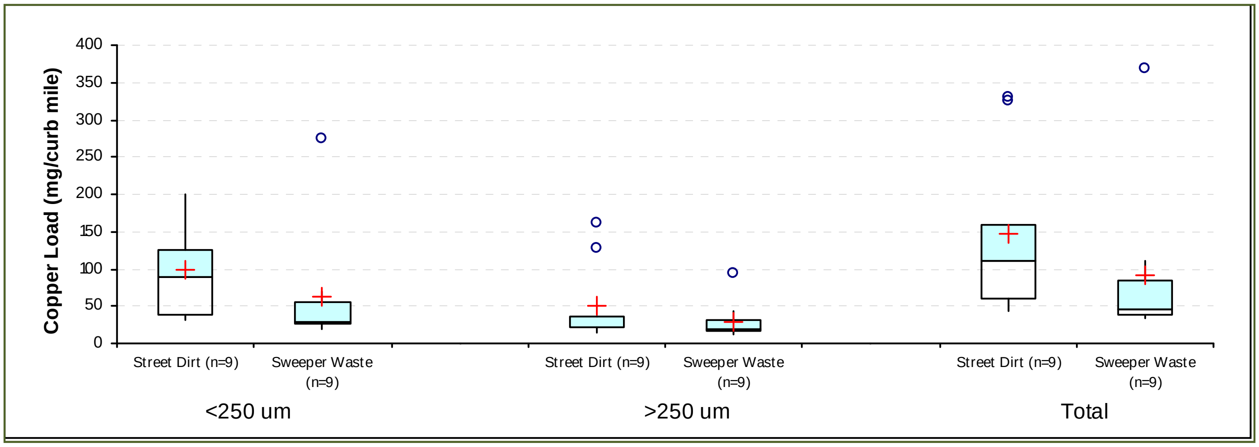

Figure 28. Box & whiskers plot comparing street dirt and sweeper waste copper load (mg/curb mile) for PM less than 250 um, greater than 250 um, and all particle diameters.

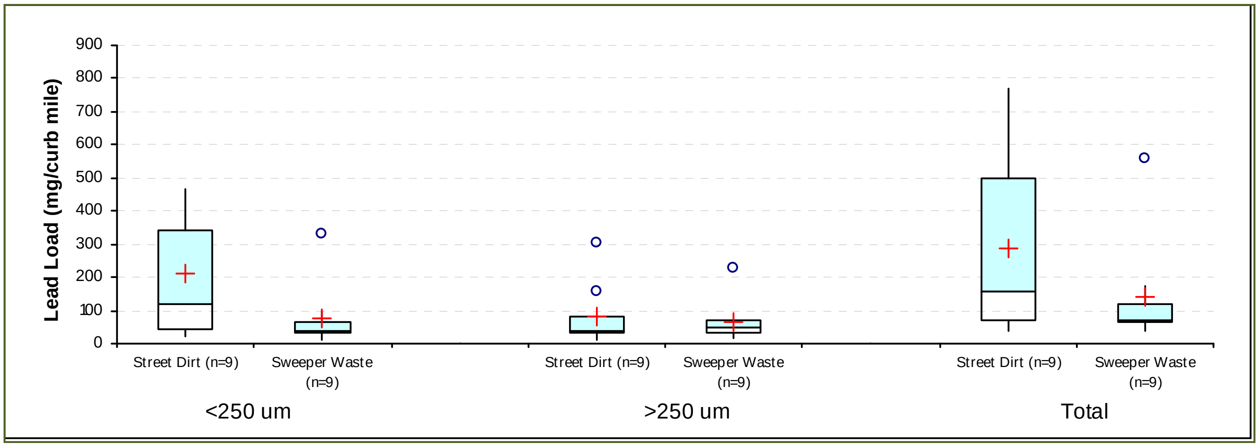

Figure 29. Box & whiskers plot comparing street dirt and sweeper waste lead load (mg/curb mile) for PM less than 250 um, greater than 250 um, and all particle diameters.

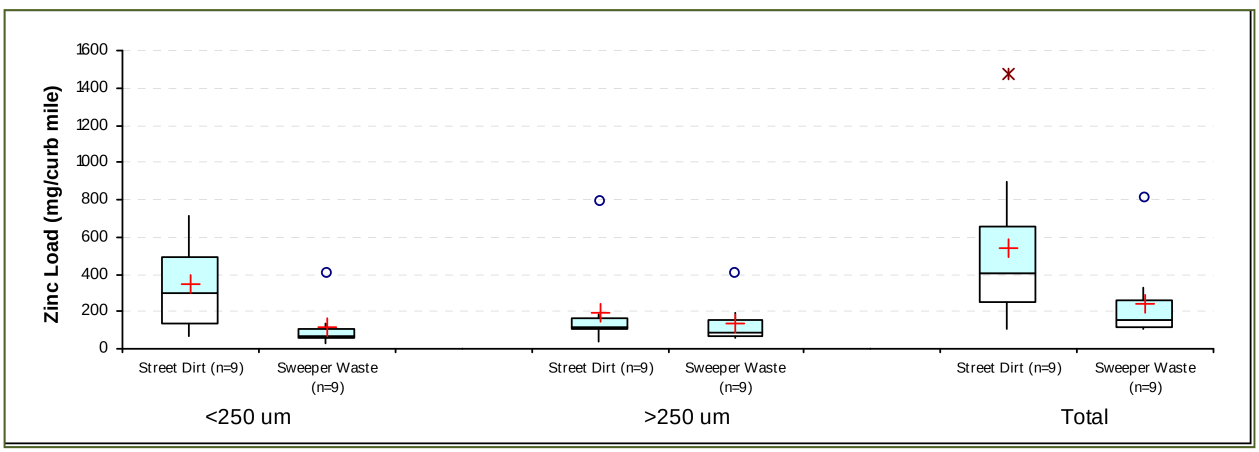

Figure 30. Box & whiskers plot comparing street dirt and sweeper waste zinc load (mg/curb mile) for PM less than 250 um, greater than 250 um, and all particle diameters.

Table 31 presents results for the Wilcoxon rank sum test comparing chromium, copper, lead, and zinc loads (mg per curb mile) for sweeper waste to street dirt for two size classes. In all cases, the median sweeper waste load is greater than or equal to 60 percent of the median street dirt load.

Table 31. Wilcoxon rank sum test results comparing chromium, copper, lead, and zinc loads for sweeper waste to street dirt for PM less than 250 μm, greater than 250 μm, and all PM (n=9 for each source type and size fraction).

PM Size	Metal	Median and interquartile range (IQR) (Load mg/kg Matl)		Median and interquartile range (IQR) (Load mg/curb mile)		Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt load (per curb mile)
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	
<250 μm	Chromium	46 (IQR=27)	18 (IQR=16)	52 (IQR=34)	13 (IQR=6.9)	SW≥0.6SD (p=0.12)
	Copper	55 (IQR=34)	55 (IQR=21)	88 (IQR=85)	29 (IQR=29)	SW≥0.6SD (p=0.31)
	Lead	120 (IQR=128)	56 (IQR=41)	120 (IQR=300)	36 (IQR=37)	SW≥0.6SD (p=0.23)
	Zinc	186 IQR=178)	113 IQR=9.7)	300 (IQR=350)	70 (IQR=51)	SW≥0.6SD (p=0.073)
>250 μm	Chromium	16 (IQR=9.6)	20 (IQR=4.1)	16 (IQR=31)	15 (IQR=11)	SW≥0.6SD (p=0.85)
	Copper	25 (IQR=11)	27 (IQR=5)	22 (IQR=16)	19 (IQR=12)	SW≥0.6SD (p=0.91)
	Lead	38 (IQR=26)	62 (IQR=27)	40 (IQR=50)	48 (IQR=41)	SW≥0.6SD (p=0.88)
	Zinc	95 IQR=22)	134 IQR=39)	119 (IQR=60)	85 (IQR=83)	SW≥0.6SD (p=0.82)
All PM	Chromium	66 (IQR=26)	37 (IQR=16)	88 (IQR=72)	26 (IQR=18)	SW≥0.6SD (p=0.20)
	Copper	88 (IQR=19)	85 (IQR=30)	110 (IQR=100)	46 (IQR=45)	SW≥0.6SD (p=0.09)
	Lead	159 (IQR=183)	115 (IQR=65)	160 (IQR=430)	71 (IQR=55)	SW≥0.6SD (p=0.41)
	Zinc	364 (IQR=187)	250 (IQR=41)	400 (IQR=410)	154 (IQR=141)	SW≥0.6SD (p=0.23)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, one-tailed test.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.

Table 32 summarizes the results of the Wilcoxon rank sum test comparing chromium, copper, lead, and zinc loads for sweeper waste to street dirt for four size classes (silt/clay, fine sand, coarse to medium sand, and gravel). In all cases, the median sweeper waste load is greater than or equal to 60 percent of the median street dirt load for all cases except the silt/clay size class for chromium and zinc.

Table 32. Wilcoxon rank sum test results comparing chromium, copper, lead, and zinc loads for sweeper waste to street dirt by size class (n=9 for each source type and size class).

Metal	Size Class	Median and interquartile range (IQR) (Load mg/kg Matl)		Median and interquartile range (IQR) (Load mg/curb mile)		Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	Load (per curb mile)
Chromium	Silt/Clay	21 (IQR=20)	6.1 (IQR=5.1)	29 (IQR=22)	4.0 (IQR=2)	**0.6SD>SW** (p=0.042)
	Fine Sand	24 (IQR=12)	12 (IQR=10)	33 (IQR=25)	8.9 (IQR=4.5)	SW≥0.6SD (p=0.18)
	Coarse Med Sand	15 (IQR=9)	18 (IQR=4.1)	15 (IQR=32)	13 (IQR=10)	SW≥0.6SD (p=0.85)
	Gravel	0.90 (IQR=0.3)	1.8 (IQR=0.99)	0.86 (IQR=0.99)	1.2 (IQR=1.3)	SW≥0.6SD (p=0.96)
Copper	Silt/Clay	31	23	49	14	SW≥0.6SD (p=0.20)

Metal	Size Class	Median and interquartile range (IQR) (Load mg/kg Matl)		Median and interquartile range (IQR) (Load mg/curb mile)		Ho: Median Sweeper Waste load ≥ 60 percent of median Street Dirt
		Street Dirt (SD)	Sweeper Waste (SW)	Street Dirt (SD)	Sweeper Waste (SW)	Load (per curb mile)
		(IQR=13)	(IQR=8.2)	(IQR=61)	(IQR=15)	
	Fine Sand	26 (IQR=9.1)	28 (IQR=12)	37 (IQR=38)	17 (IQR=14)	SW≥0.6SD (p=0.38)
	Coarse Med Sand	21 (IQR=4.1)	21 (IQR=5.5)	20 (IQR=14)	16 (IQR=6.6)	SW≥0.6SD (p=0.90)
	Gravel	2.2 (IQR=1.6)	4.5 (IQR=3.6)	2.9 (IQR=2.3)	2.9 (IQR=4.9)	SW≥0.6SD (p=0.91)
Lead	Silt/Clay	44 (IQR=65)	17 (IQR=6.6)	59 (IQR=150)	10 (IQR=10)	SW≥0.6SD (p=0.07)
	Fine Sand	56 (IQR=52)	40 (IQR=32)	63 (IQR=130)	26 (IQR=29)	SW≥0.6SD (p=0.41)
	Coarse Med Sand	33 (IQR=24)	54 (IQR=25)	39 (IQR=48)	43 (IQR=38)	SW≥0.6SD (p=0.90)
	Gravel	2.3 (IQR=1.5)	4.2 (IQR=3)	2.2 (IQR=3.3)	2.6 (IQR=2.6)	SW≥0.6SD (p=0.91)
Zinc	Silt/Clay	73 (IQR=109)	43 (IQR=6.6)	170 (IQR=220)	28 (IQR=23)	**0.6SD>SW** (p=0.029)
	Fine Sand	111 (IQR=59)	71 (IQR=9.6)	140 (IQR=140)	42 (IQR=28)	SW≥0.6SD (p=0.13)
	Coarse Med Sand	86 (IQR=22)	120 (IQR=50)	110 (IQR=50)	74 (IQR=74)	SW≥0.6SD (p=0.75)
	Gravel	5.3 (IQR=11)	18 (IQR=5.3)	6.7 (IQR=8.9)	11 (IQR=12)	SW≥0.6SD (p=0.97)

Bold values indicate that the null hypothesis (Ho) is false. Wilcoxon rank sum test, alpha=0.05, one-tailed test.
0.6SD>SW indicates Ho is false.
SW>0.6SD indicates Ho is true; the sweeper waste median is significantly greater than 60 percent of the street dirt median.

5.3.2 COMPARING MEASURED METAL LOAD DISTRIBUTION BY SIZE CLASS AND LAND USE

This section compares the measured metal load distributions by size class and land use. The measured load (mg per kg material) distribution is the portion of metal within each size class without accounting for any loading rates (e.g. these loads have not been adjusted to a curb mile basis, see Section 4.4.2).

Comparing measured loads by size class Figure 31, Figure 32, and Figure 33 present the measured metal loading distribution results graphically for copper, lead, and zinc.

The street dirt fine PM (<250 µm) contains over sixty percent of the load for chromium, copper, lead, and zinc.

- For catch basin sediment: 49, 67, 56, and 57 percent of the mass of chromium, copper, lead, and zinc metal is found in the fine PM (<250 microns), respectively.
- For street dirt: 64, 69, 73, and 67 percent of the mass of chromium, copper, lead, and zinc metal is found in the fine PM (<250 microns), respectively.
- For sweeper waste: 47, 63, 57, and 45 percent of the mass of chromium, copper, lead, and zinc metal is found in the fine PM (<250 microns), respectively.

The load distribution shape tends to be similar for catch basin and sweeper waste, possibly indicating the influence of the removal process. The shape of the load distribution curve for street dirt is distinctly different; more evenly distributed across the silt/clay, fine sand and coarse to medium sand with minimal distribution in the gravel size class.

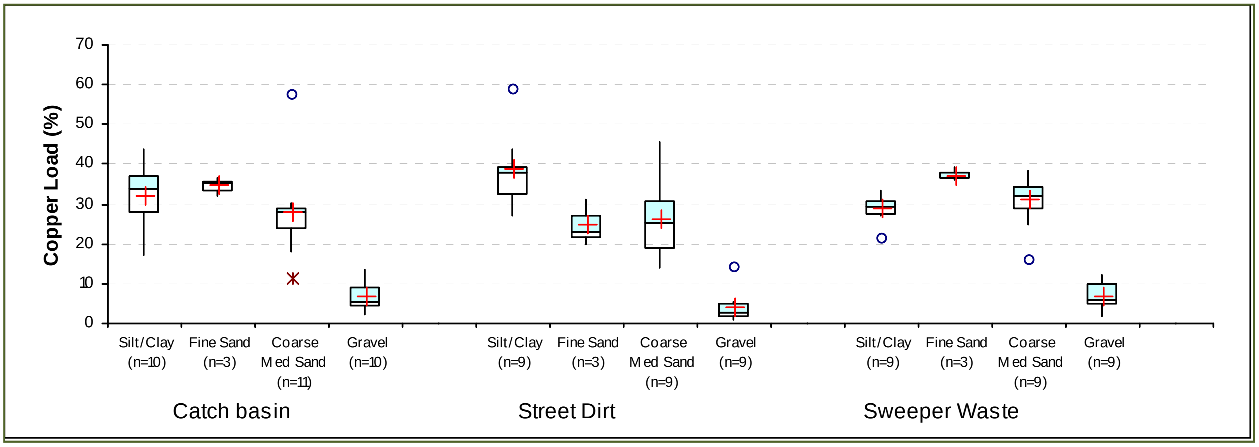

Figure 31. Box & whisker plot of copper load distribution by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

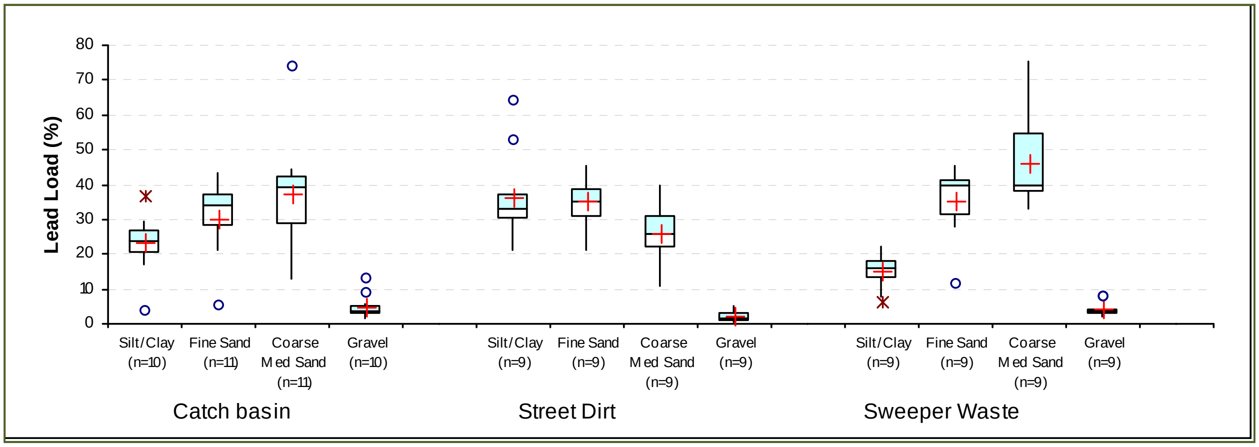

Figure 32. Box & whisker plot of lead load distribution by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

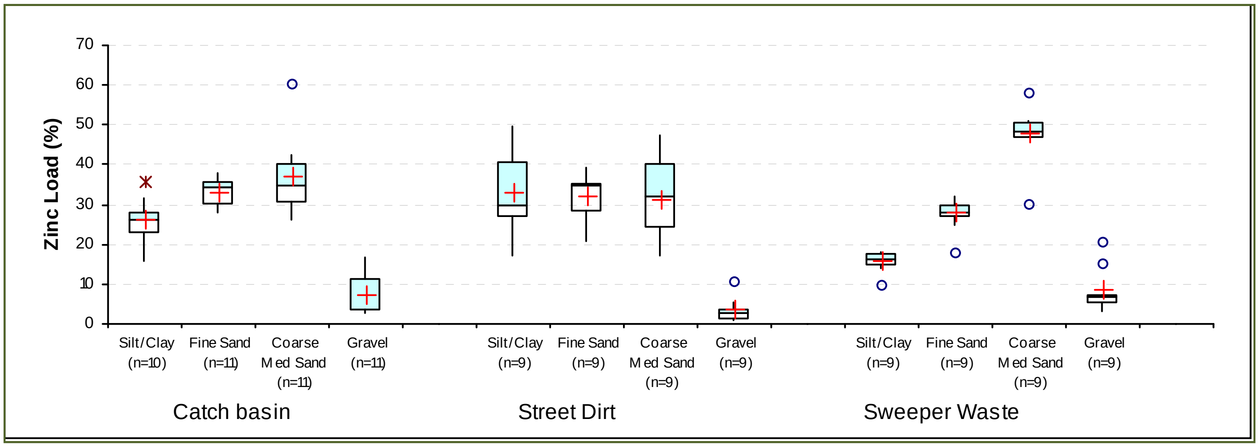

Figure 33. Box & whisker plot of zinc load distribution by size class (silt/clay, fine sand, coarse to medium sand, and gravel) for three sources (catch basin sediment, street dirt, and sweeper waste).

Comparing measured loads by land use Metal loads for each source (catch basin sediment (CB), street dirt (SD), and sweeper waste (SW)) for each study test site (Columbia City South (CCS), Diagonal Duwamish East (DDE), and West Seattle North (WSN)) are presented in Appendix D.

For each parameter, the Diagonal Duwamish East study basin, which is industrial land use, generally has higher measured load than either of the other study basins, which are both residential. The catch basin sediment loads from the Diagonal Duwamish East study basin are noticeably greater.

6 Summary and Conclusions

Available street dirt and sweeper waste loads can be used to estimate the potential benefits gained by implementing a regenerative air street sweeping program. Additional information on newer sweeping technologies and street dirt and sweeper waste loads by size fraction may aid stormwater managers in the Pacific Northwest to determine the appropriate mix of structural stormwater BMPs and regenerative air street sweeping to optimize water quality benefits in a cost-effective manner.

For this study, the distribution of seven metals by particle grain size fraction from three sources (catch basin sediment, street dirt, and street sweeper contents) evaluated during the Seattle Street Sweeping Pilot Study were analyzed.

The targeted action, street sweeping with a regenerative air sweeper, has the potential to reduce stormwater chromium, copper, lead, and zinc loads associated with particle sizes less than fine sand (<250 μm) and the bulk of the potentially toxic chromium, copper, lead, and zinc loads from city streets, inferring that regenerative air sweeping at the appropriate frequency (once every 2 weeks in Seattle) has the potential to provide a level of treatment similar to structural stormwater BMPs.

It is also noted that the study results are generally similar to those collected by others from across the nation, with a few exceptions:

- The study results indicate that local street dirt may have a larger portion of fines, consistent with the PSD for local stormwater (Ecology 2008). Street dirt results reported by others indicate approximately 30 percent fines (<250 μm) while the Pilot Study found approximately 47 percent fines. Sweeper waste results for two experiments by Breault (2005) found 18 to 27 percent fines (<250 μm) while the Pilot Study found 36 percent fines.

- The study results indicate that street dirt fine PM (<250 μm), which is approximately 47 percent, contains approximately 64 to 73 percent of the metal load while sweeper waste, which is approximately 36 percent fine PM, contains 45 to 63 percent of the metal load. The distribution of PM less than 250 µm in diameter, as median values, for catch basin, street dirt, and sweeper waste is 51, 47, and 36 percent, respectively. The distribution of the metals load for PM less than 250 µm in diameter for catch basin, street dirt, and sweeper waste is 67, 69, and 63 percent, respectively for copper; 56, 73, and 57 percent, respectively for lead; and 57, 67, and 45 percent, respectively for zinc.

The recommendation to continue development and implementation of the Street Sweeping for Water Quality Program is made with consideration to developing methodology that will support estimating the site specific conditions and sweeping operation characteristics needed to maximize the pollutant load removed by sweeping in the most cost effective manner. Study variables may include frequency, seasonality (in particular, dry season, leaf season, and wet season), and sweeping velocity.

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Appendices

Appendix A. Pilot study results showing loading rates (kg/curb mile).

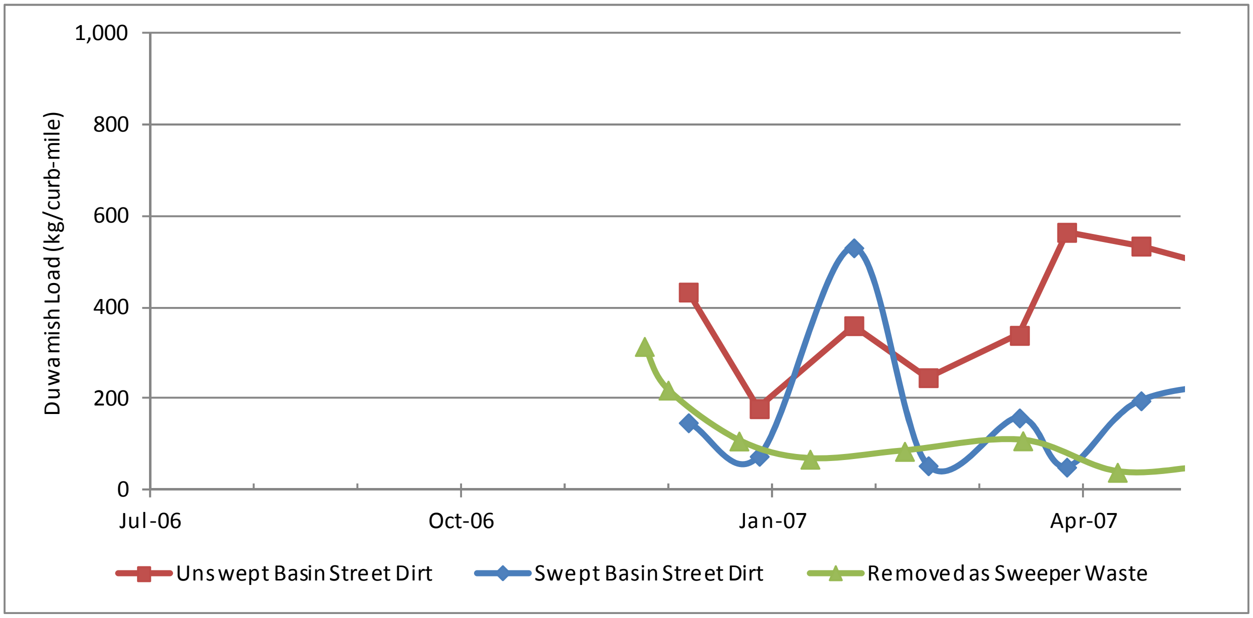

Figure 34. Loading (kg/curb mile) for unswept and swept basin street dirt and sweeper waste removed for the Duwamish Diagonal basin.

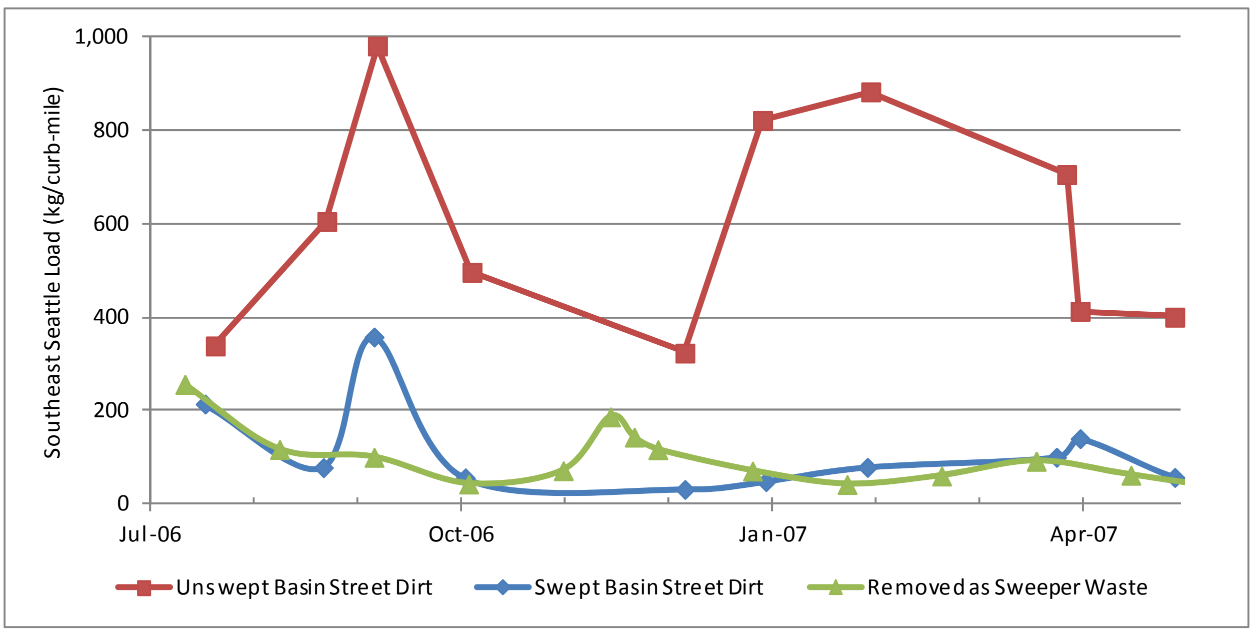

Figure 35. Loading (kg/curb mile) for unswept and swept basin street dirt and sweeper waste removed for the Southeast Seattle basin.

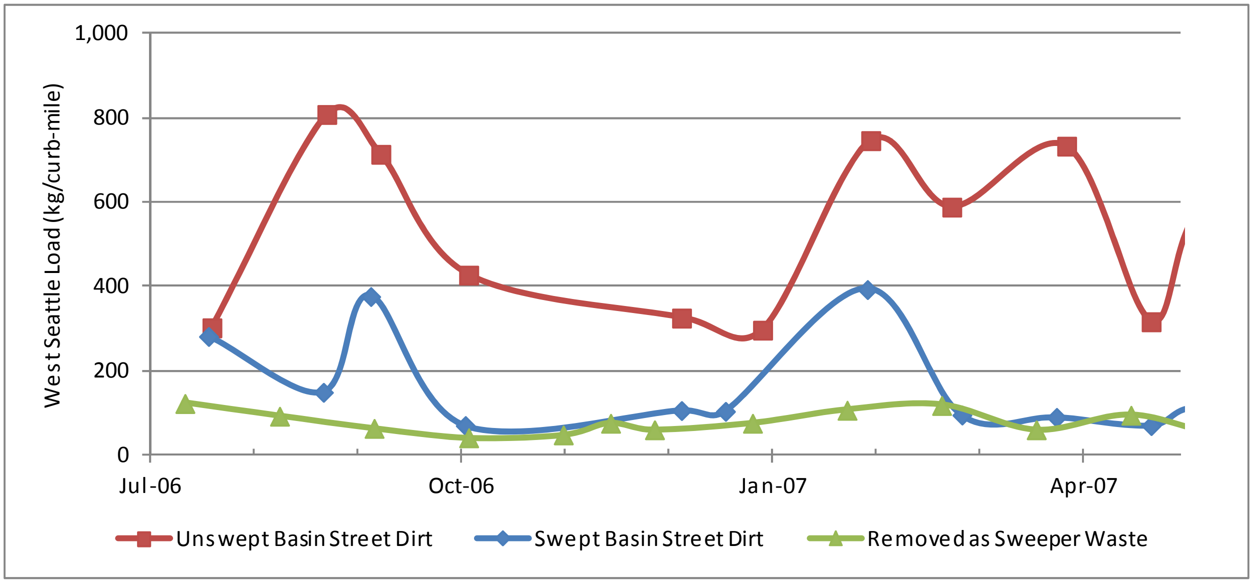

Figure 36. Loading (kg/curb mile) for unswept and swept basin street dirt and sweeper waste removed for the West Seattle basin.

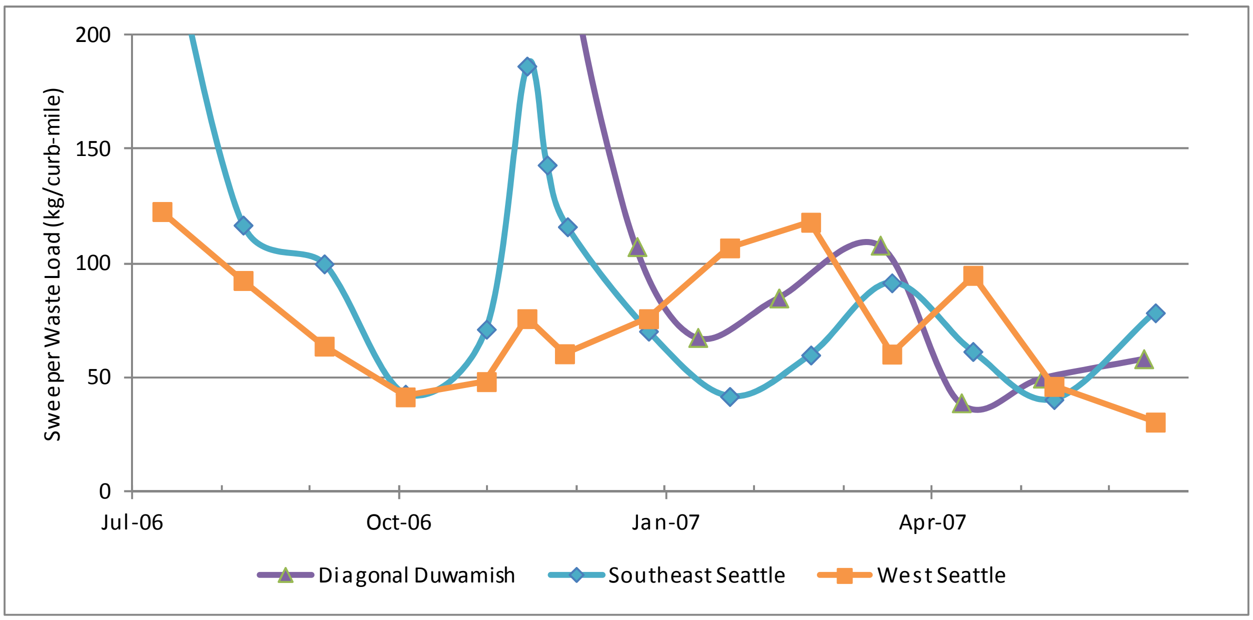

Figure 37. Comparison of sweeper waste load removal rates (kg/curb mile) for three basins.

Appendix B. Figures Showing Comparison of Unswept and Swept Basin Geometric Mean Particle Size Diameter.

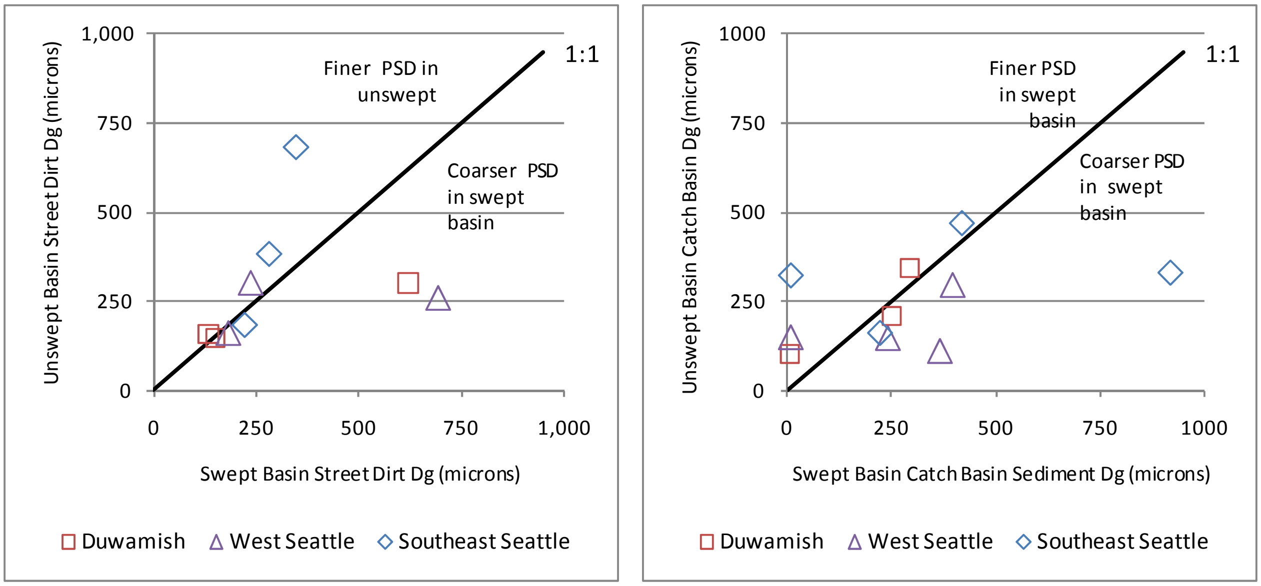

Figure 38. Comparison of unswept and swept basin geometric mean (Dg) for street dirt (left) and catch basin sediment (right) by location.

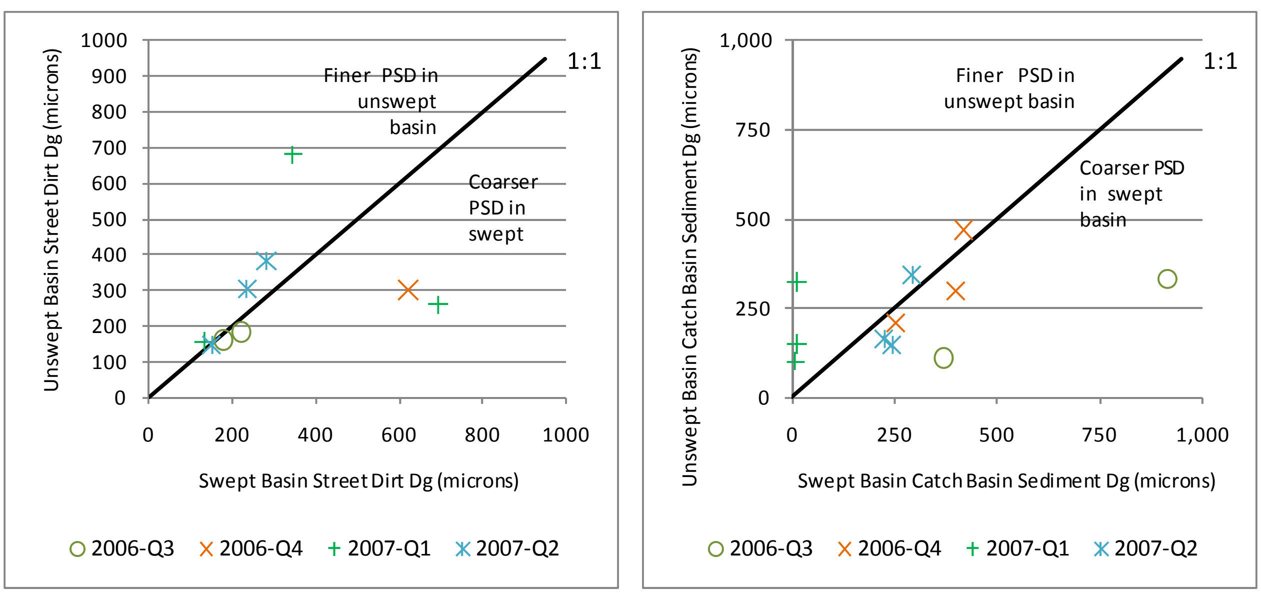

Figure 39. Comparison of unswept and swept basin geometric mean (Dg) for street dirt (left) and catch basin sediment (right) by sample quarter.

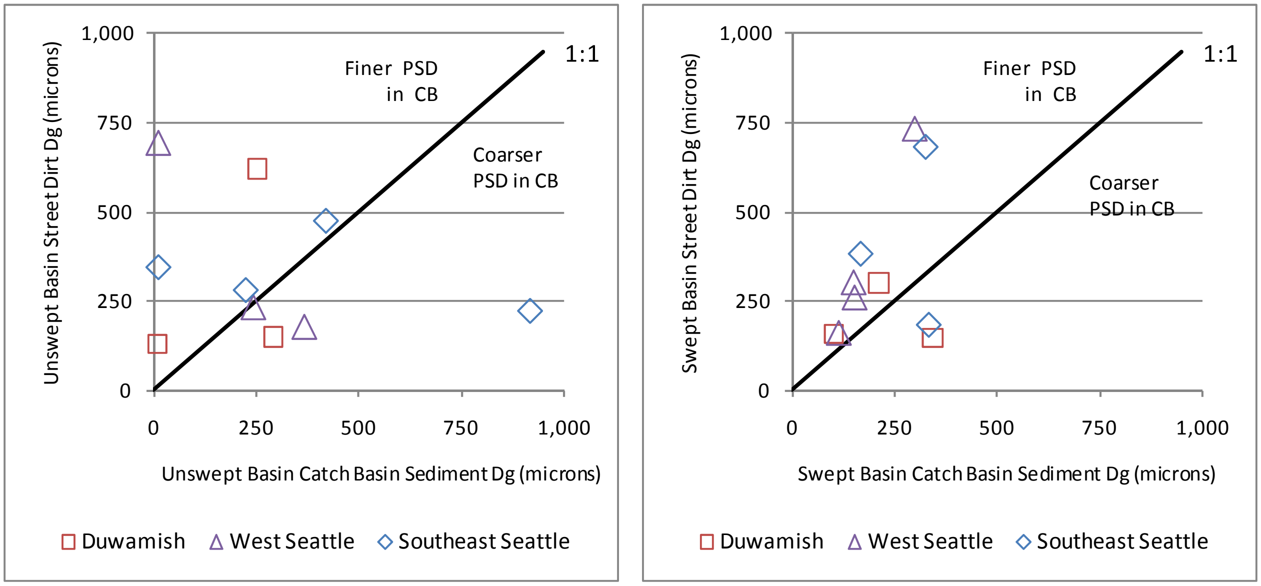

Figure 40. Comparison of street dirt and catch basin sediment geometric mean (Dg) for unswept (left) and swept (right) basins by location.

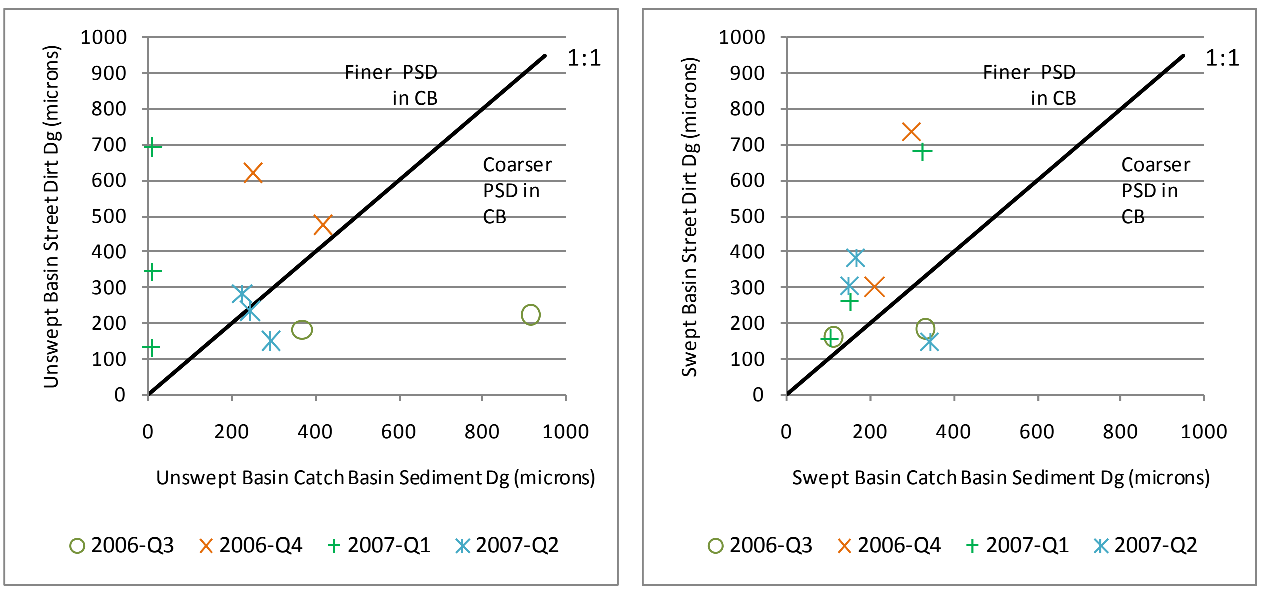

Figure 41. Comparison of street dirt and catch basin sediment geometric mean (Dg) for unswept (left) and swept (right) basins by sample quarter.

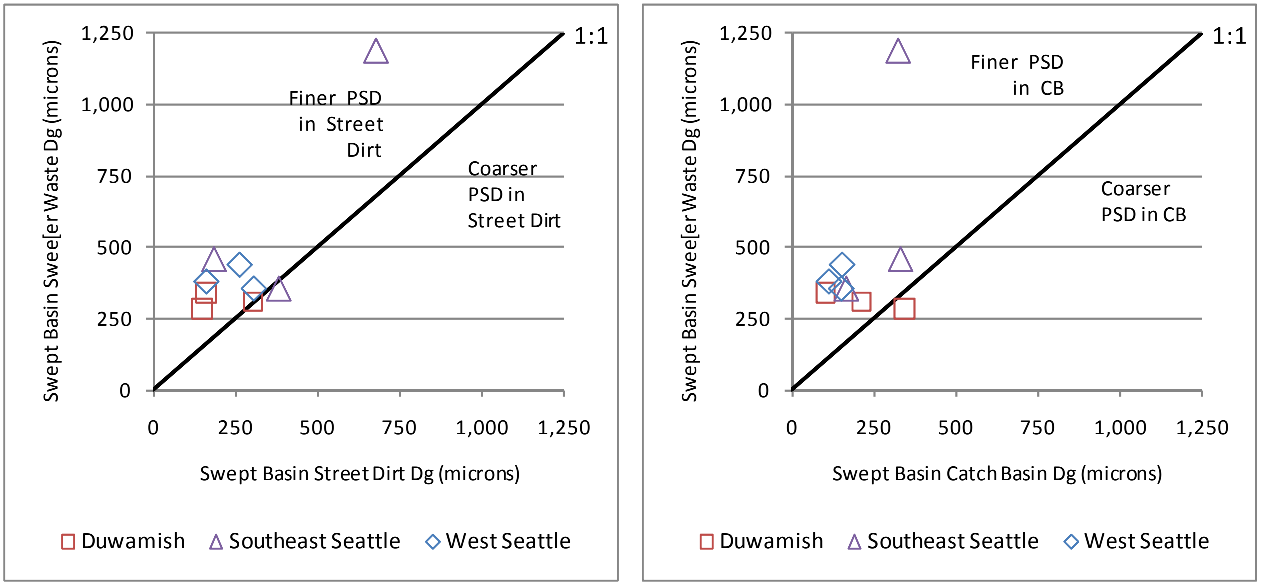

Figure 42. Comparison of sweeper waste geometric mean (Dg) with street dirt (left) and catch basin sediment (right) by location.

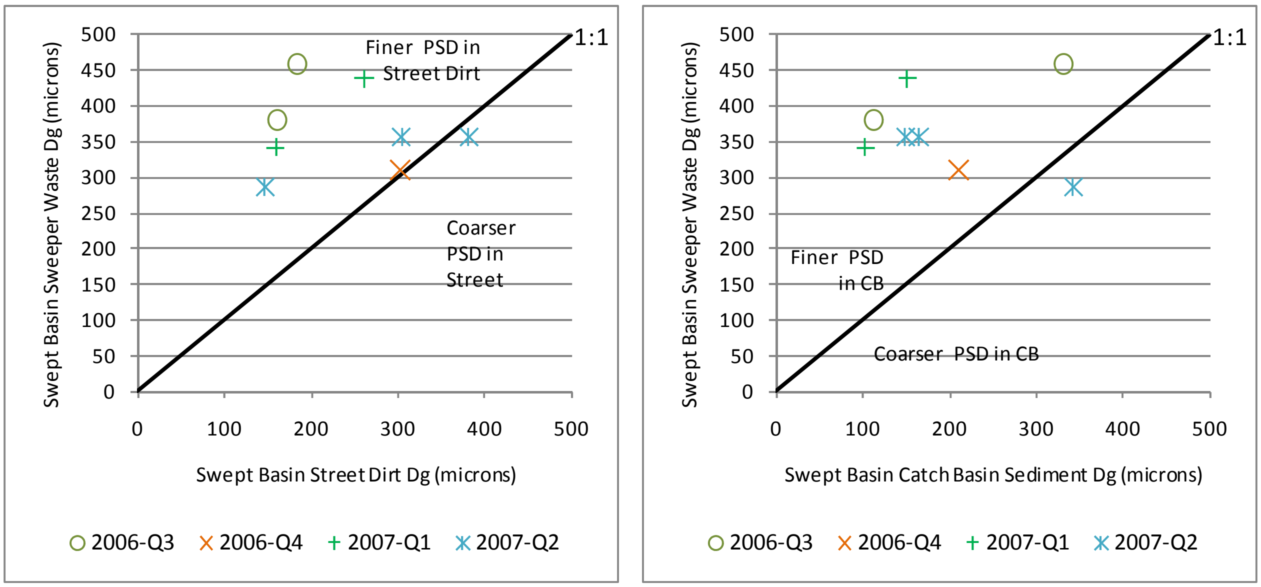

Figure 43. Comparison of sweeper waste geometric mean (Dg) with street dirt (left) and catch basin sediment (right) by sample quarter.

Appendix C. Box & whisker plots showing concentrations for each study basin and source type by size class.

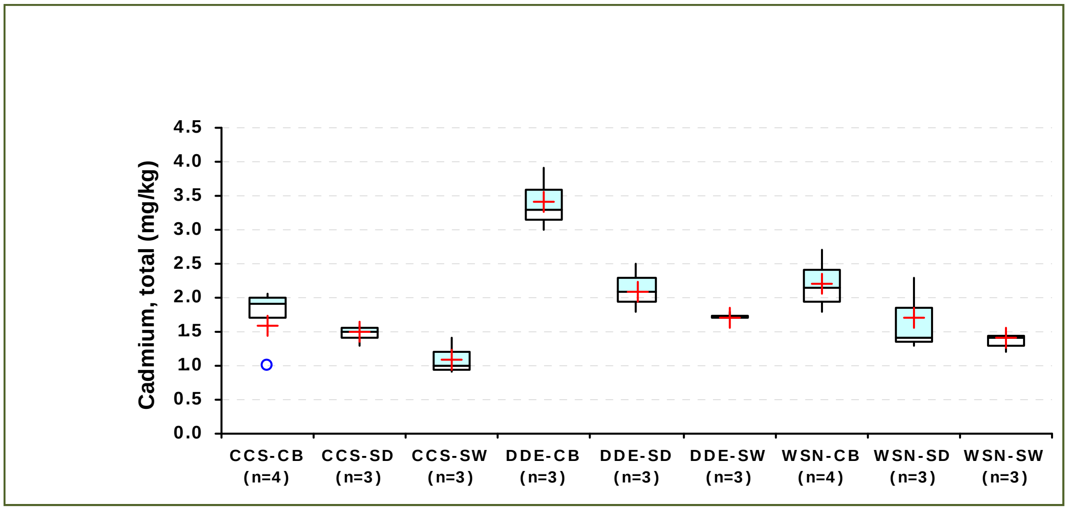

Figure 44. Cadmium concentrations for each study basin and source type for size class silt/clay.

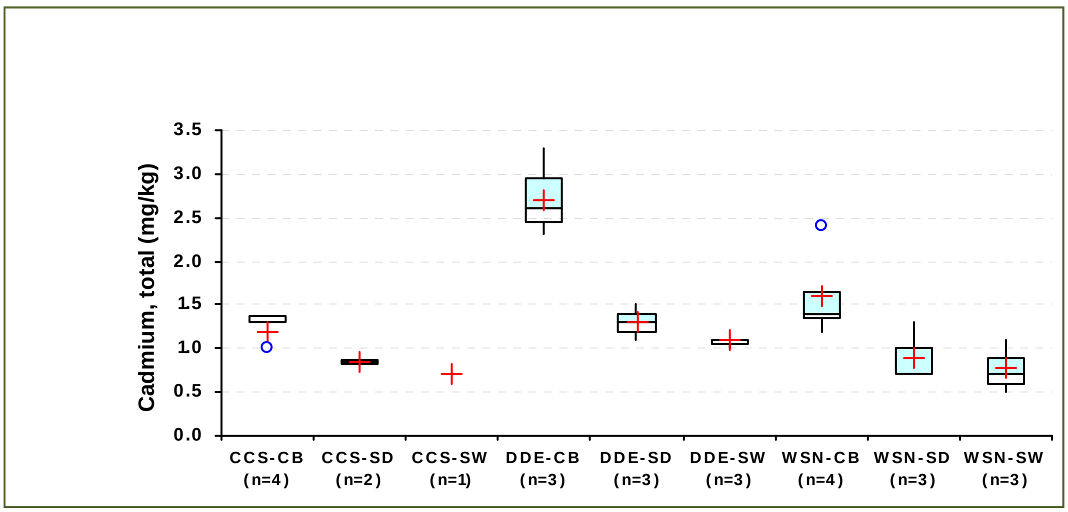

Figure 45. Cadmium concentrations for each study basin and source type for size class fine sand.

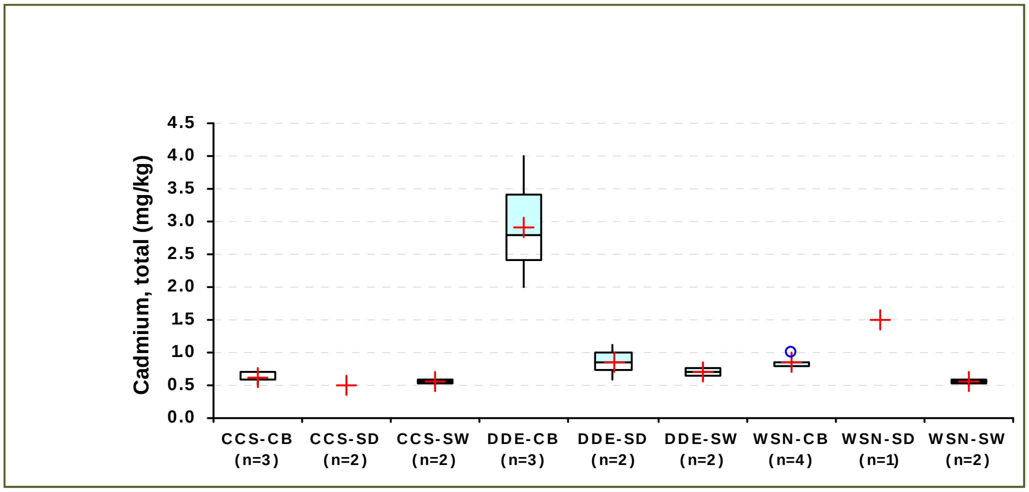

Figure 46. Cadmium concentrations for each study basin and source type for size class medium to coarse sand.

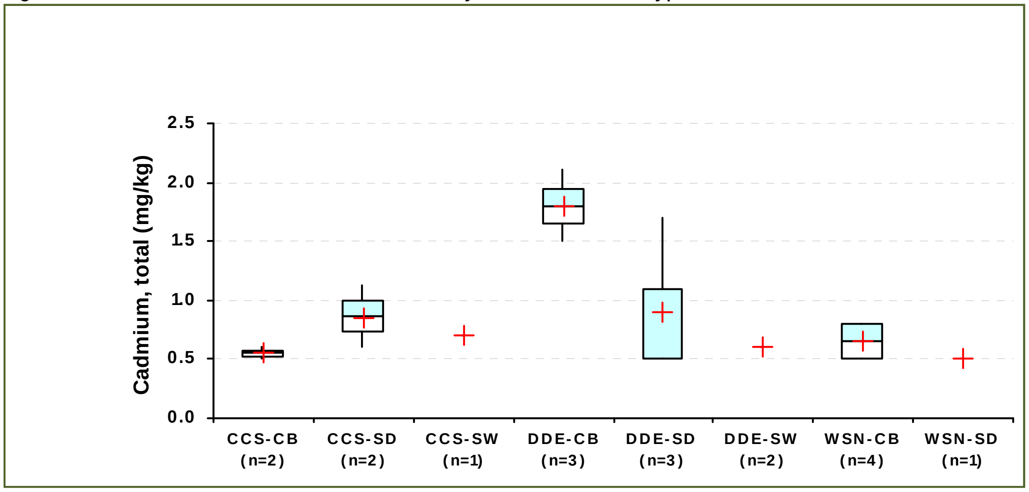

Figure 47. Cadmium concentrations for each study basin and source type for size class gravel.

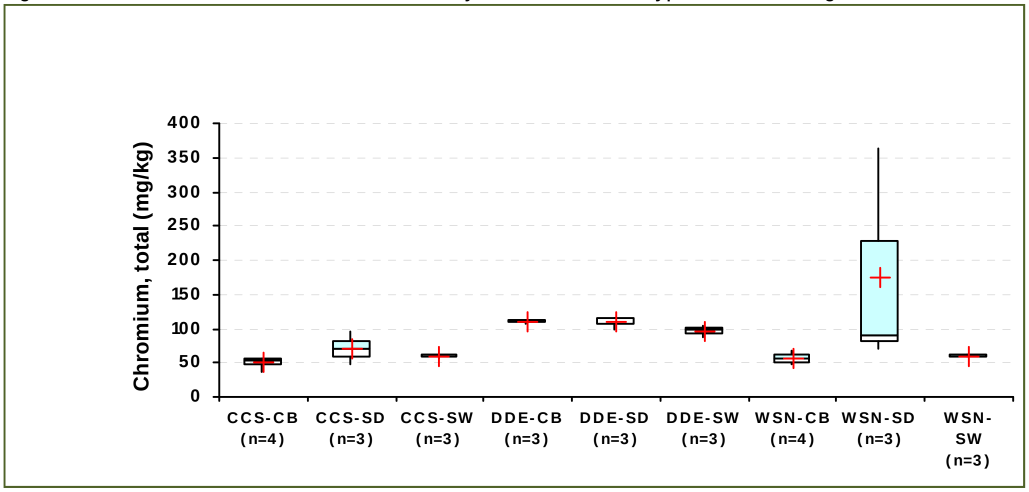

Figure 48. Chromium concentrations for each study basin and source type for size class silt/clay.

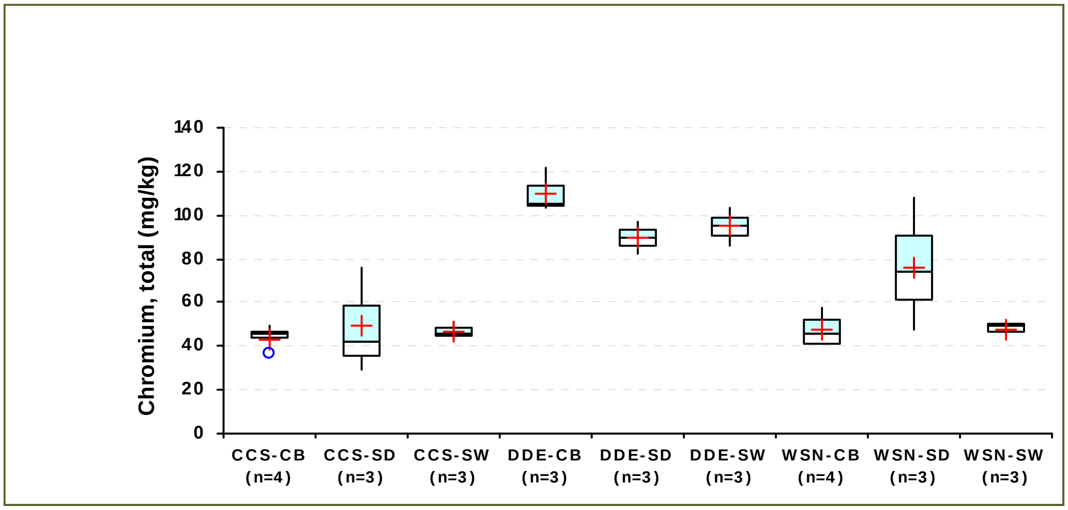

Figure 49. Chromium concentrations for each study basin and source type for size class fine sand.

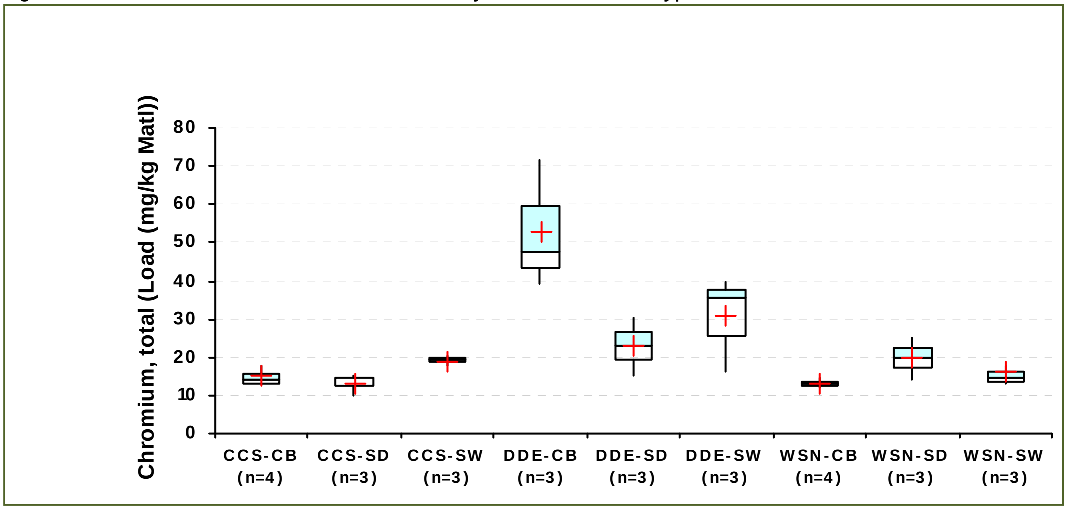

Figure 50. Chromium concentrations for each study basin and source type for size class coarse to medium sand.

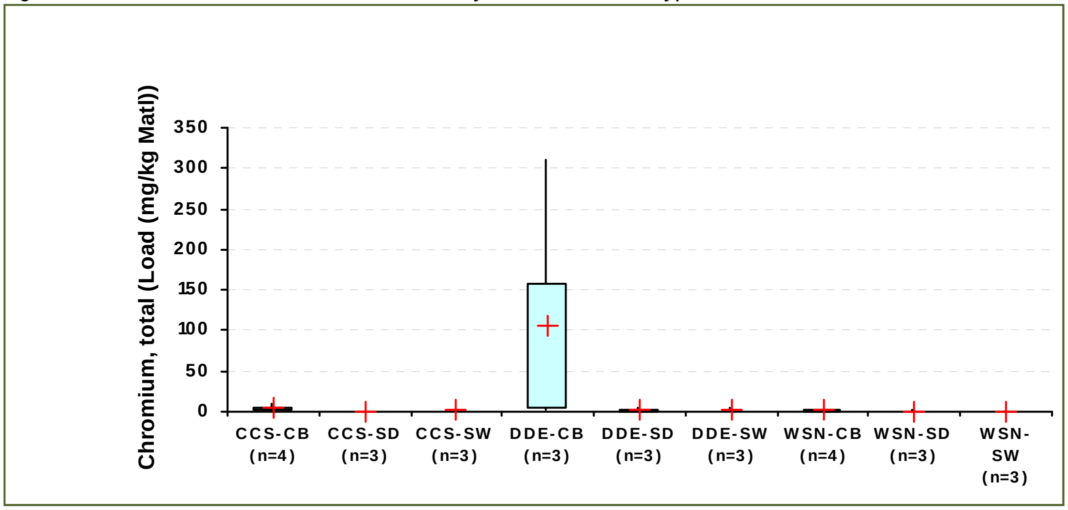

Figure 51. Chromium concentrations for each study basin and source type for size class gravel.

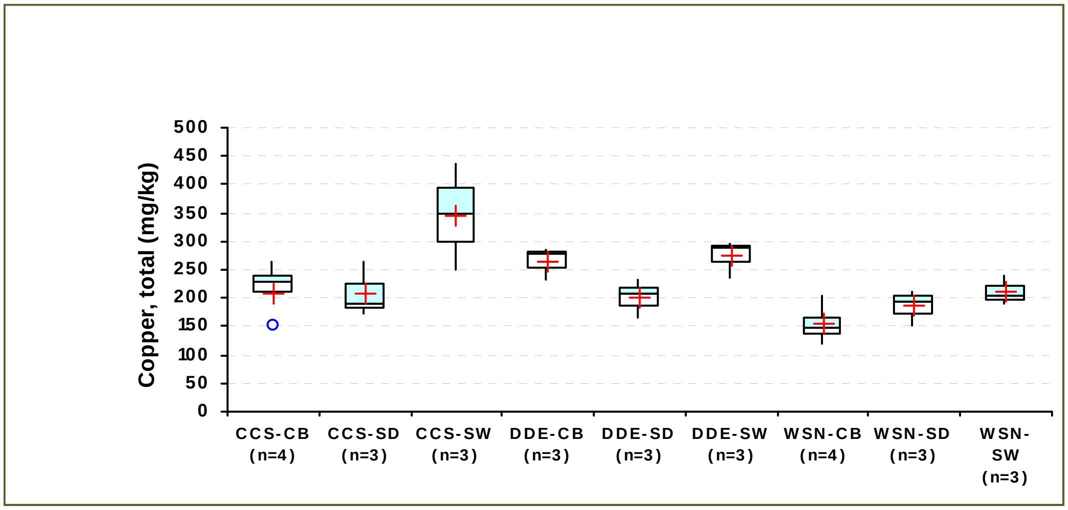

Figure 52. Copper concentrations for each study basin and source type for size class silt/clay.

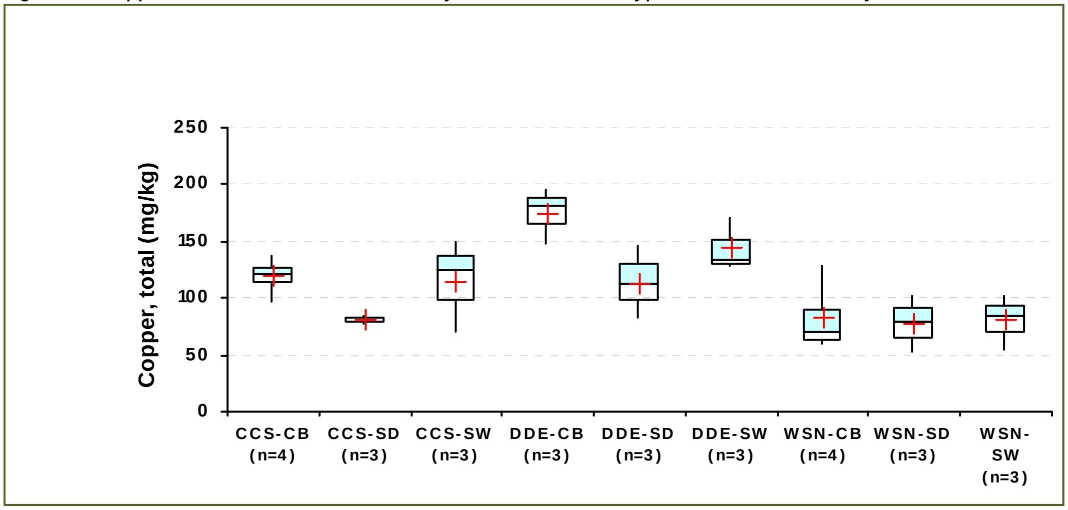

Figure 53. Copper concentrations for each study basin and source type for size class fine sand.

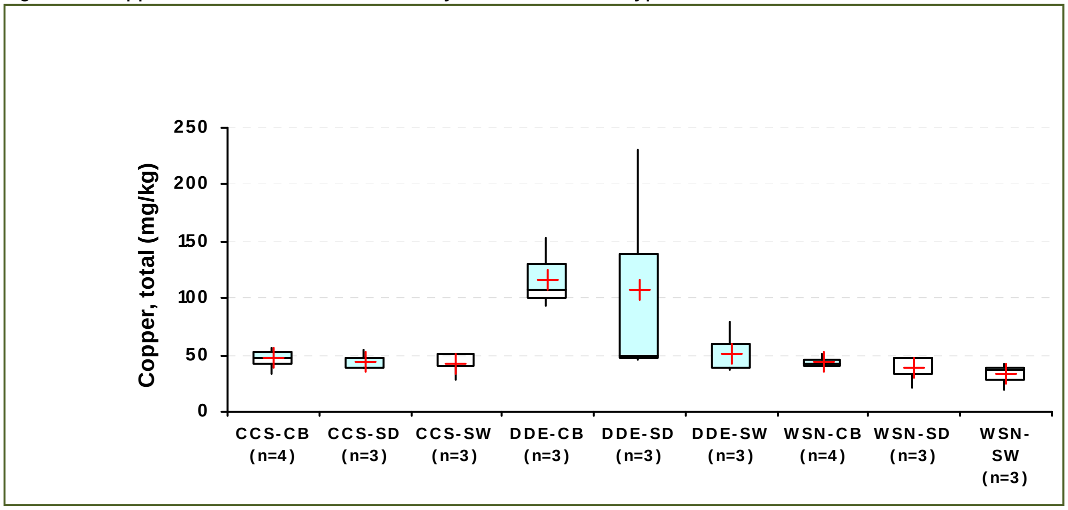

Figure 54. Copper concentrations for each study basin and source type for size class coarse to medium sand.

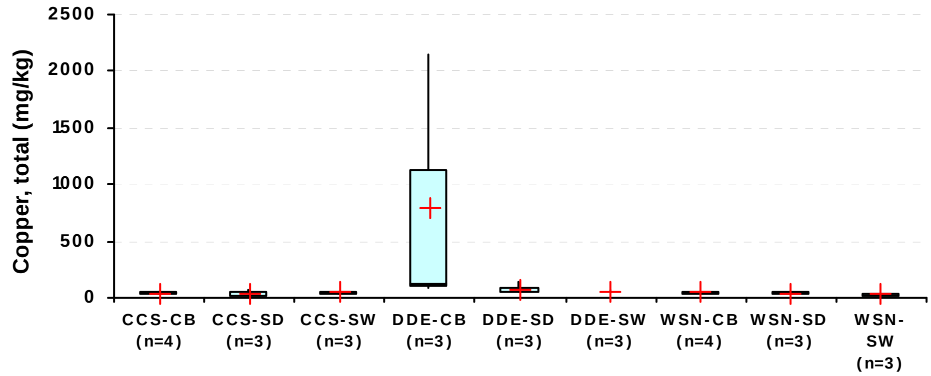

Figure 55. Copper concentrations for each study basin and source type for size class gravel.

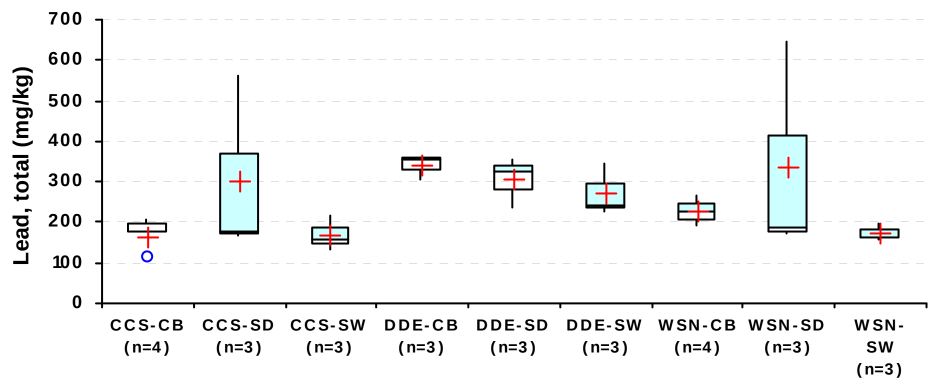

Figure 56. Lead concentrations for each study basin and source type for size class silt/clay.

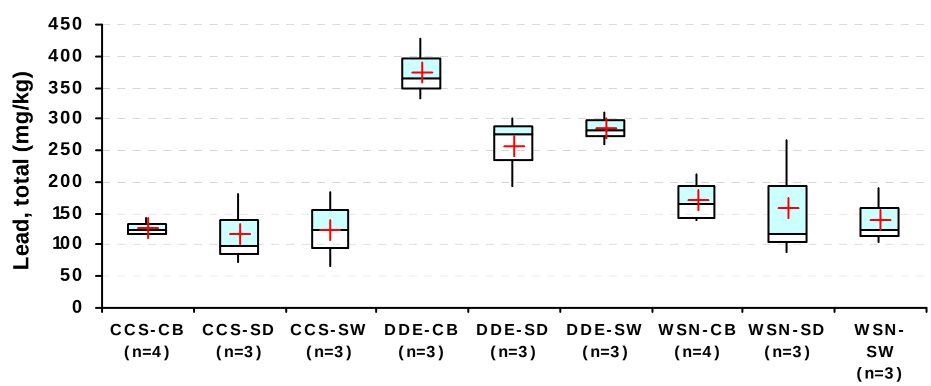

Figure 57. Lead concentrations for each study basin and source type for size class fine sand.

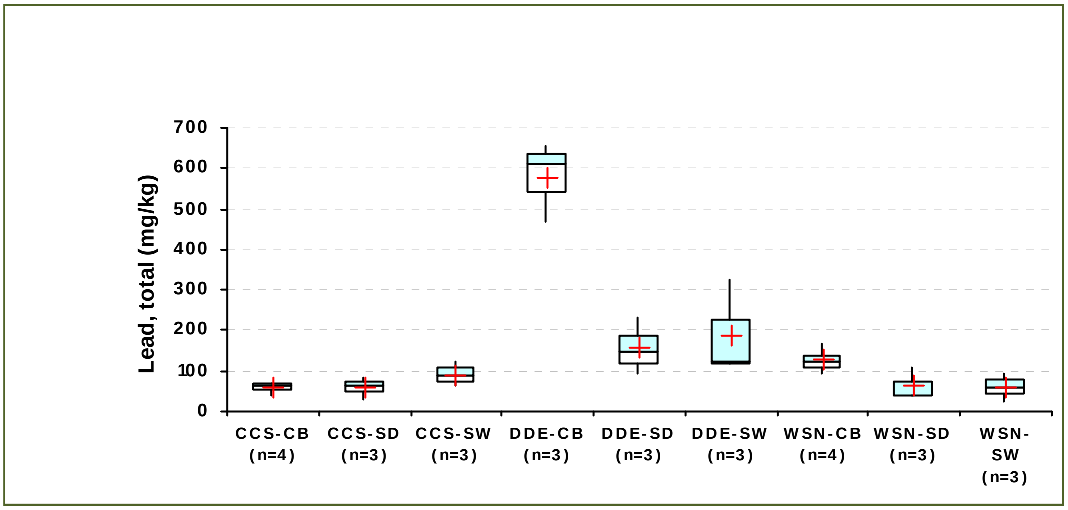

Figure d concentrations for each study basin and source type for size class coarse to medium sand.

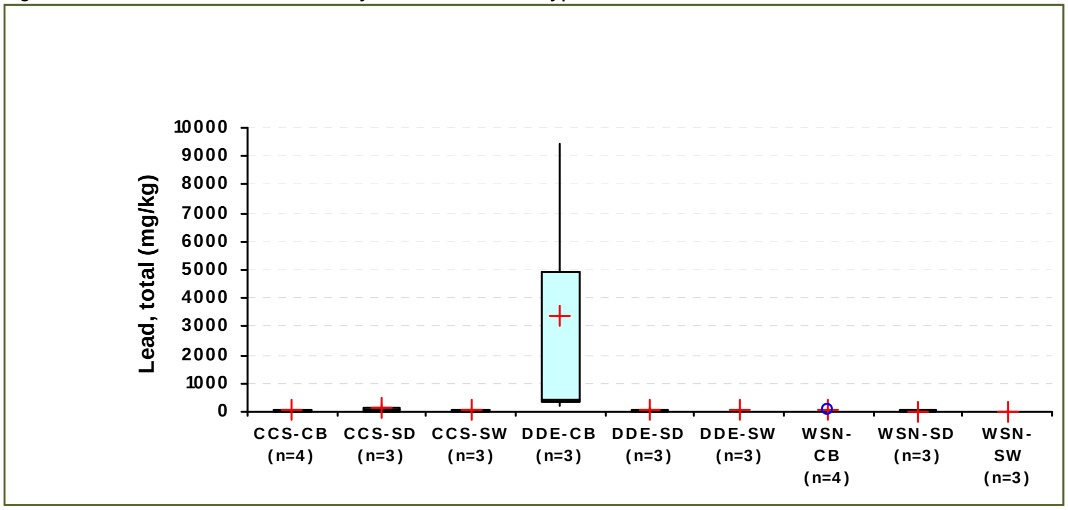

Figure 58. Lead concentrations for each study basin and source type for size class gravel.

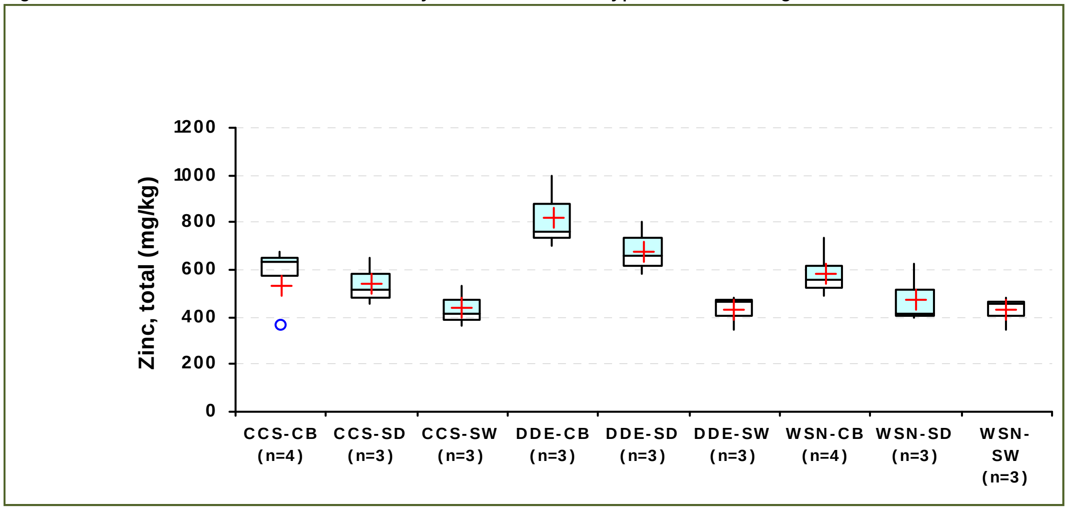

Figure 59. Zinc concentrations for each study basin and source type for size class silt/clay.

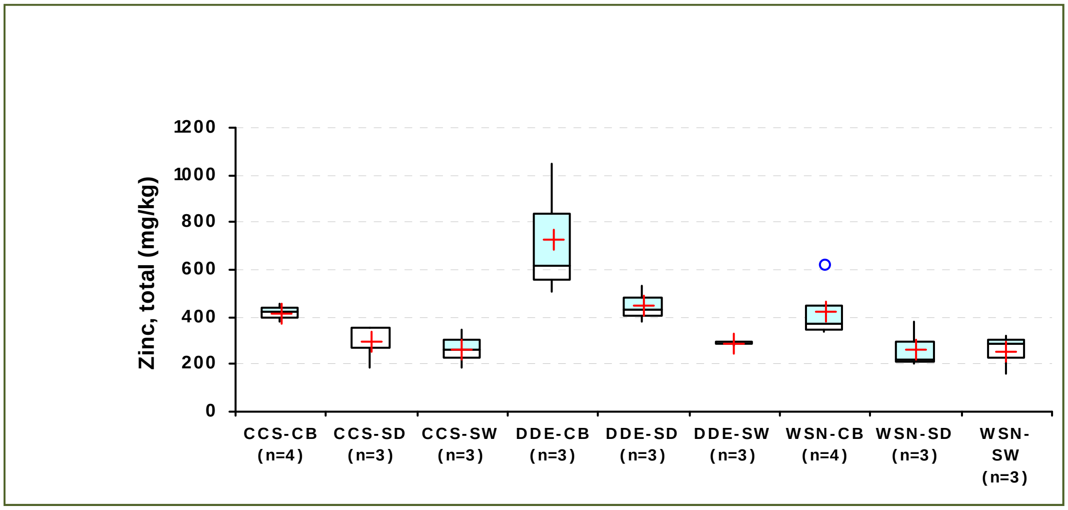

Figure 60. Zinc concentrations for each study basin and source type for size class fine sand.

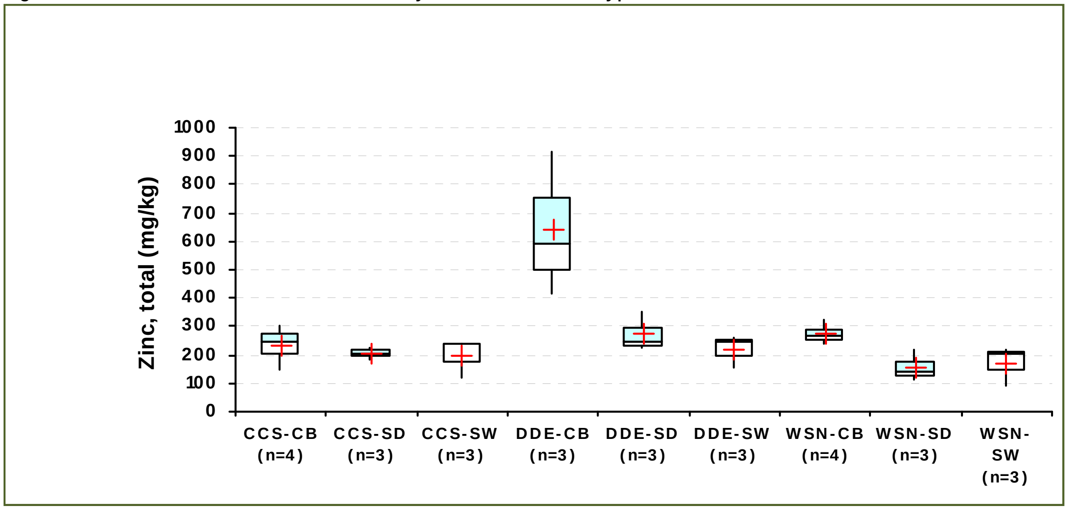

Figure 61. Zinc concentrations for each study basin and source type for size class coarse to medium sand.

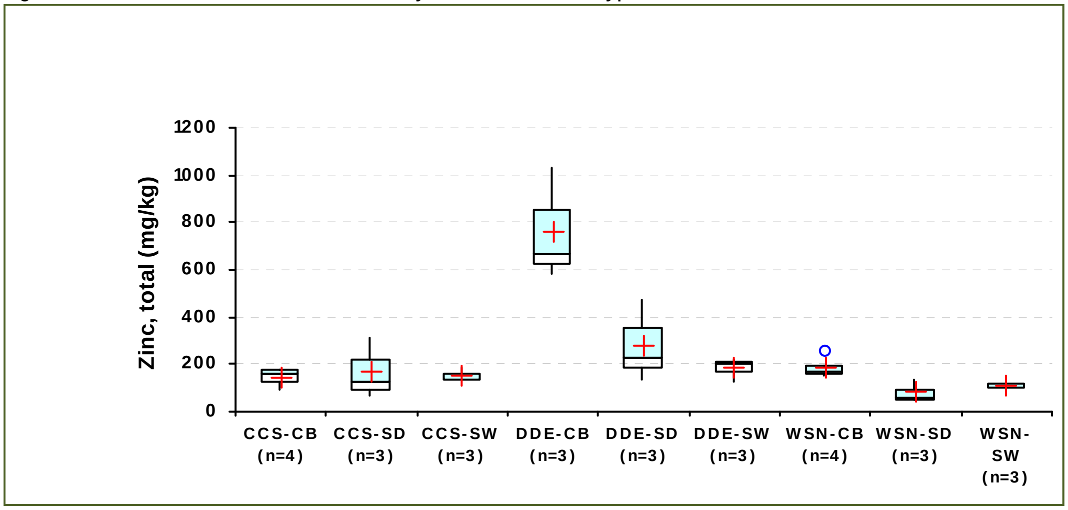

Figure 62. Zinc concentrations for each study basin and source type for size class gravel.

Appendix D. Box & whisker plot of measured metal loads for each size class, source type, and land use (mg per kg material).

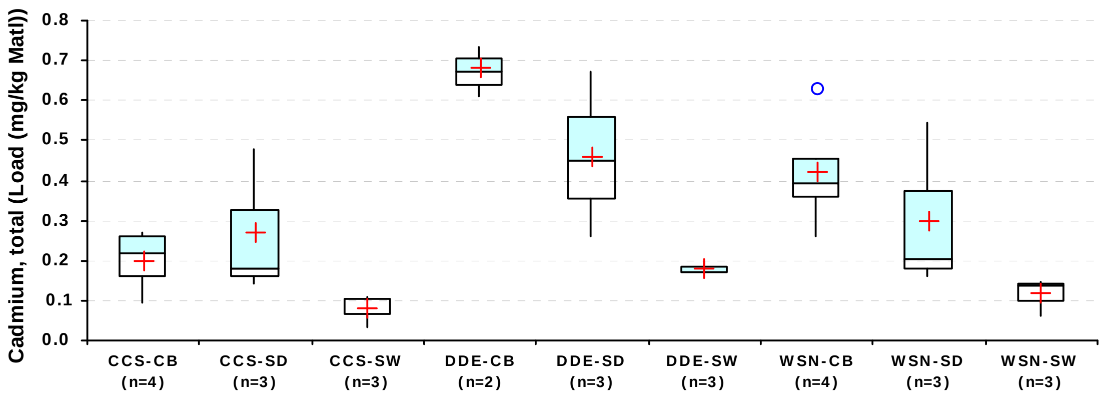

Figure 63. Box & whisker plot of cadmium load (mg/kg material) for size class silt/clay for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

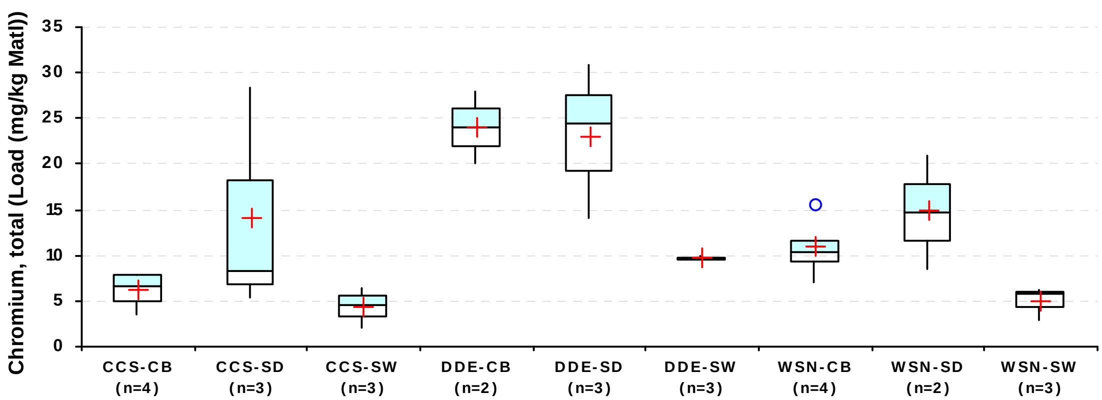

Figure 64. Box & whisker plot of chromium load (mg/kg material) for size class silt/clay for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

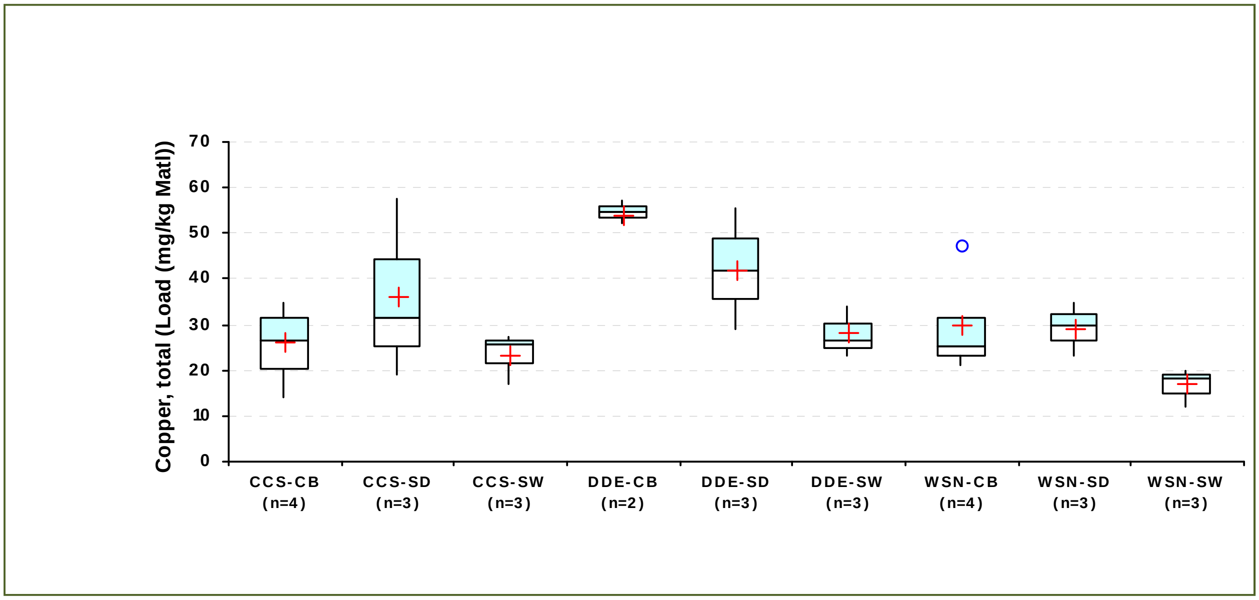

Figure 65. Box & whisker plot of copper load (mg/kg material) for size class silt/clay for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

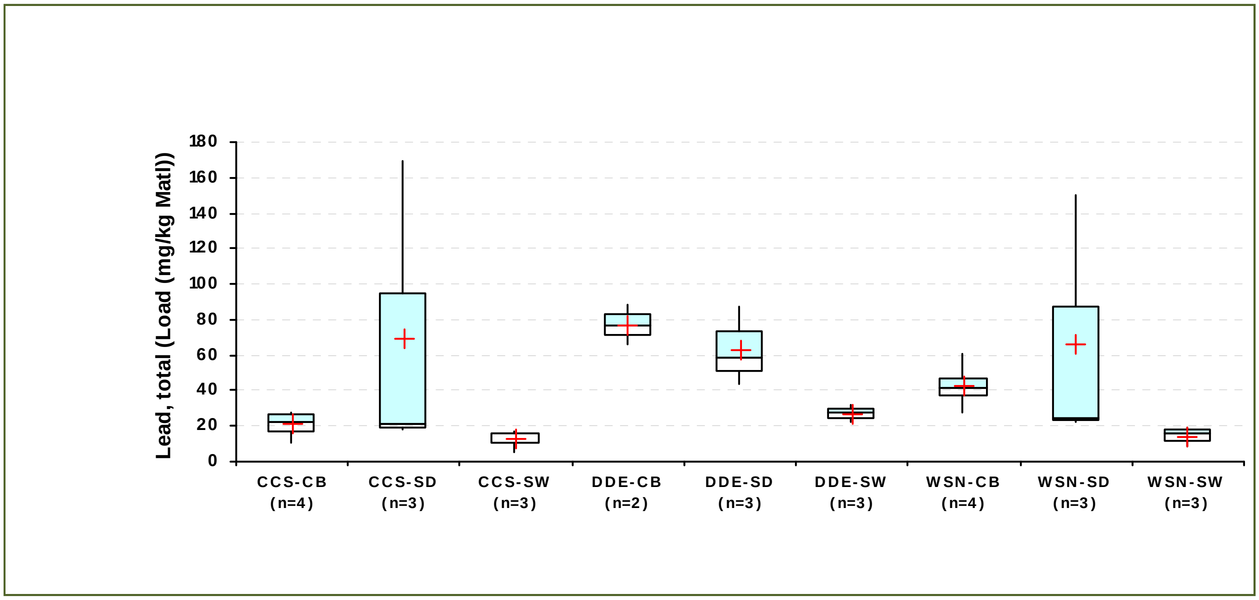

Figure 66. Box & whisker plot of lead load (mg/kg material) for size class silt/clay for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

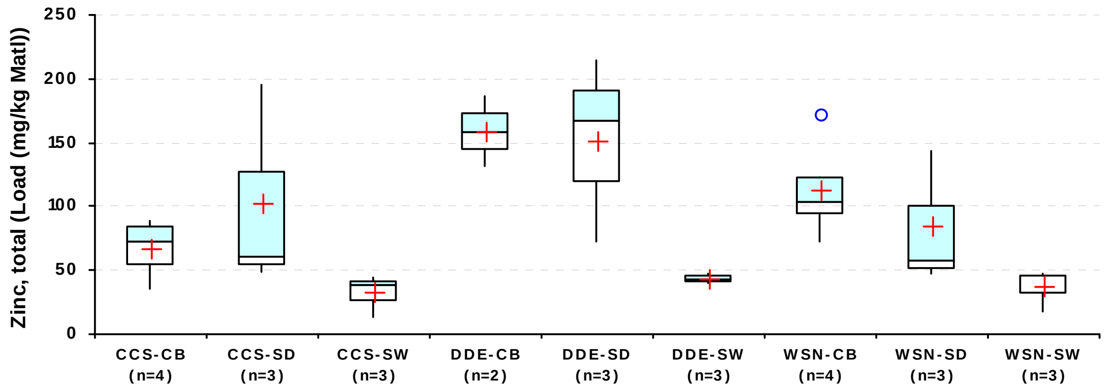

Figure 67. Box & whisker plot of zinc load (mg/kg material) for size class silt/clay for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

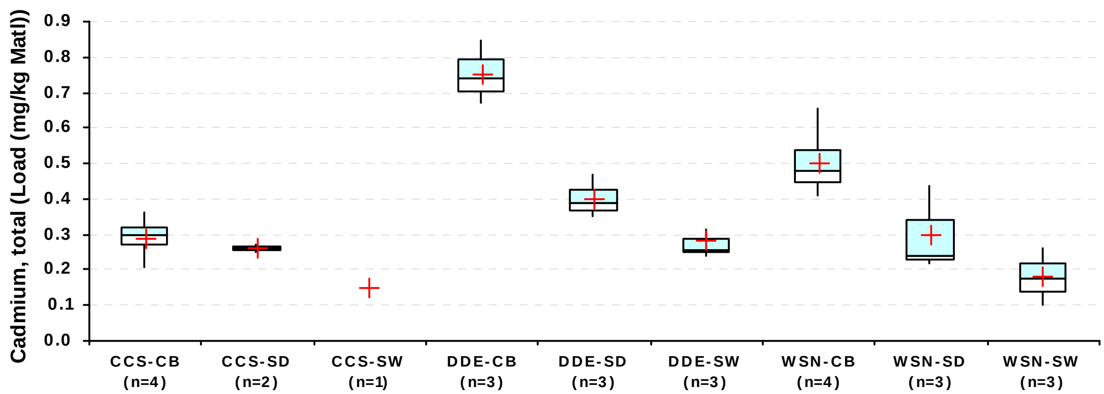

Figure 68. Box & whisker plot of cadmium load (mg/kg material) for size class fine sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

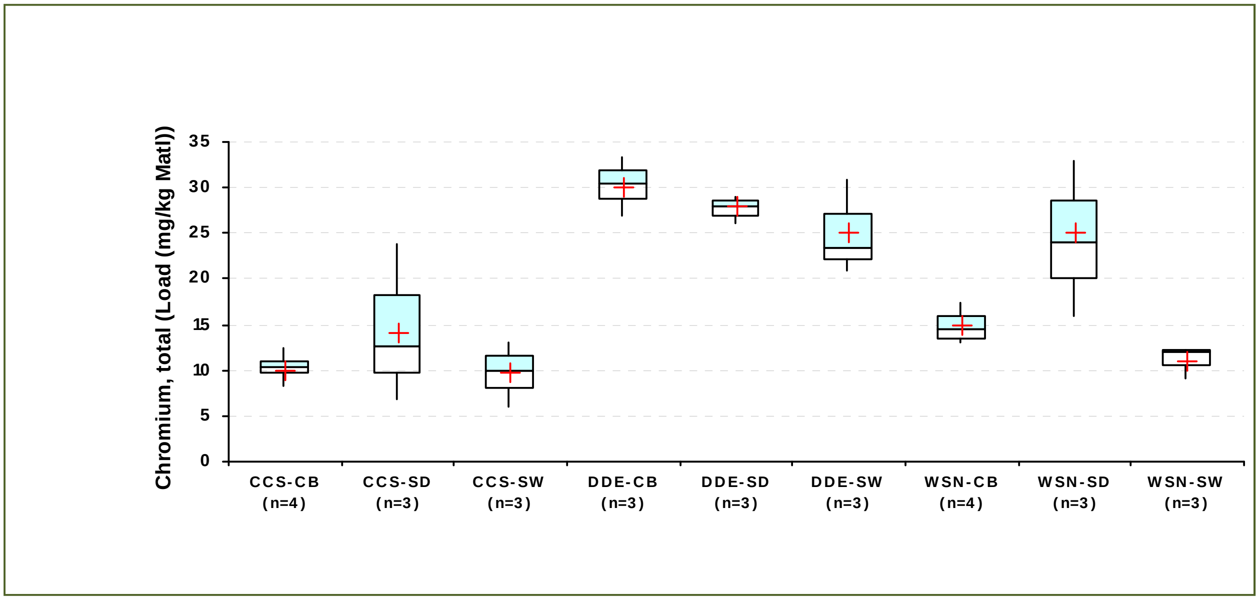

Figure 69. Box & whisker plot of chromium load (mg/kg material) for size class fine sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

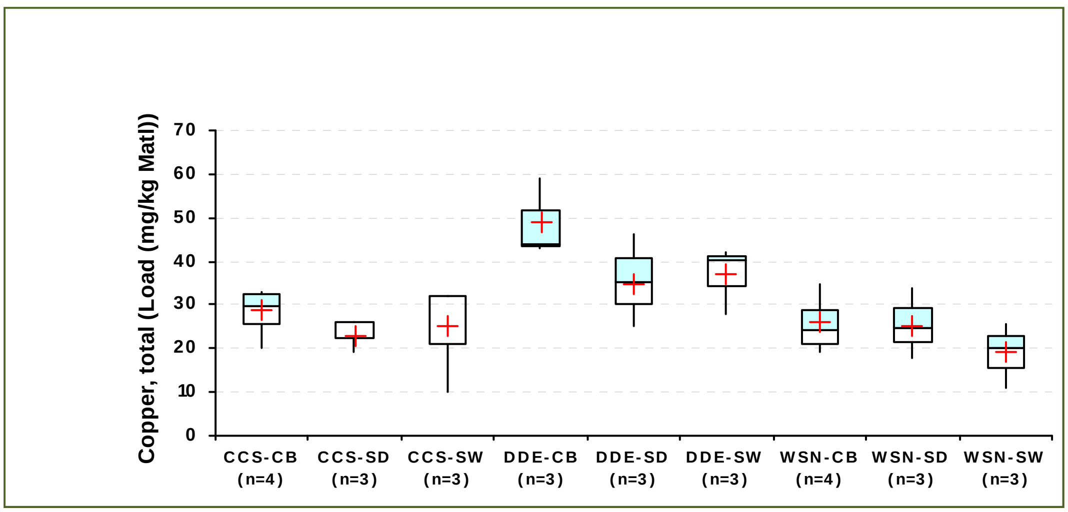

Figure 70. Box & whisker plot of copper load (mg/kg material) for size class fine sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

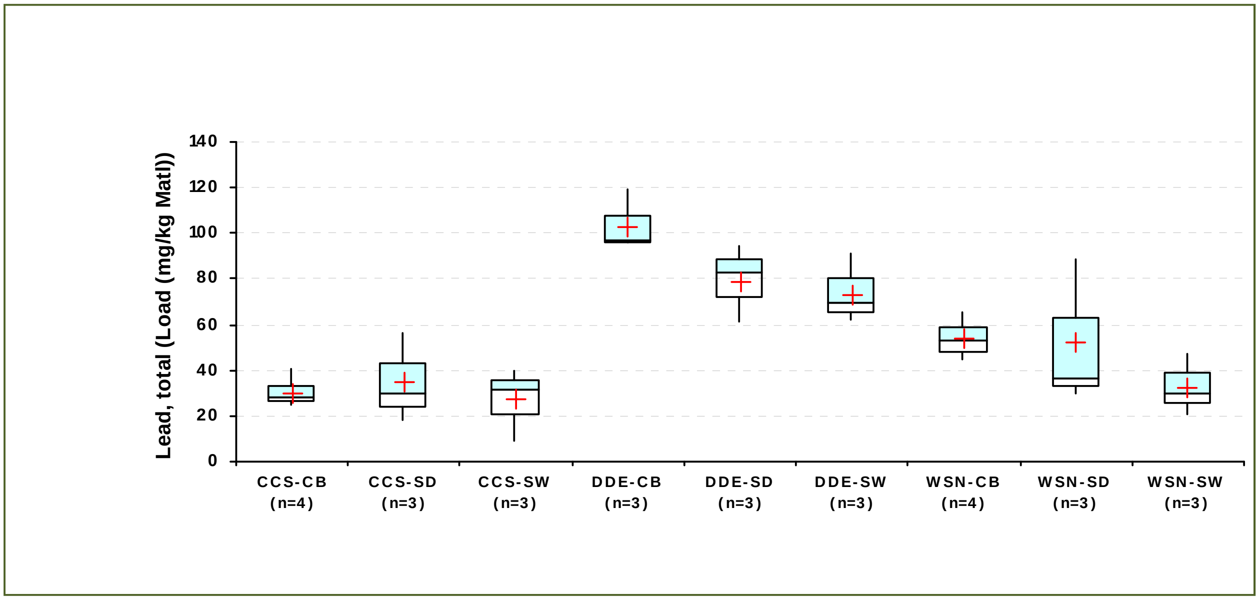

Figure 71. Box & whisker plot of lead load (mg/kg material) for size class fine sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

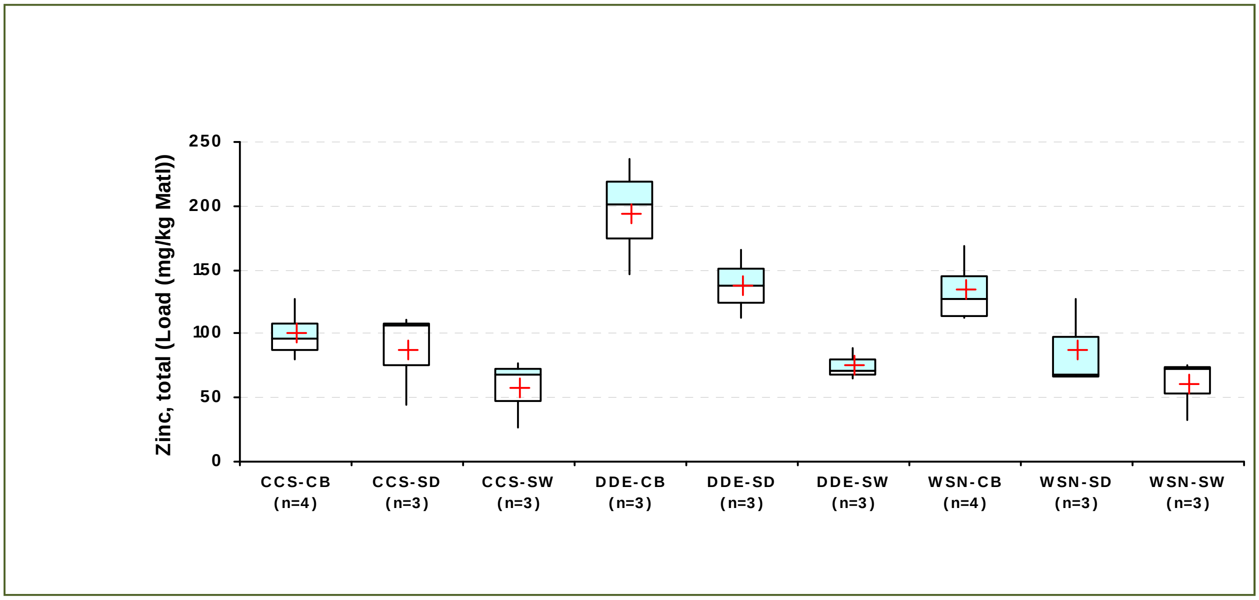

Figure 72. Box & whisker plot of zinc load (mg/kg material) for size class fine sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

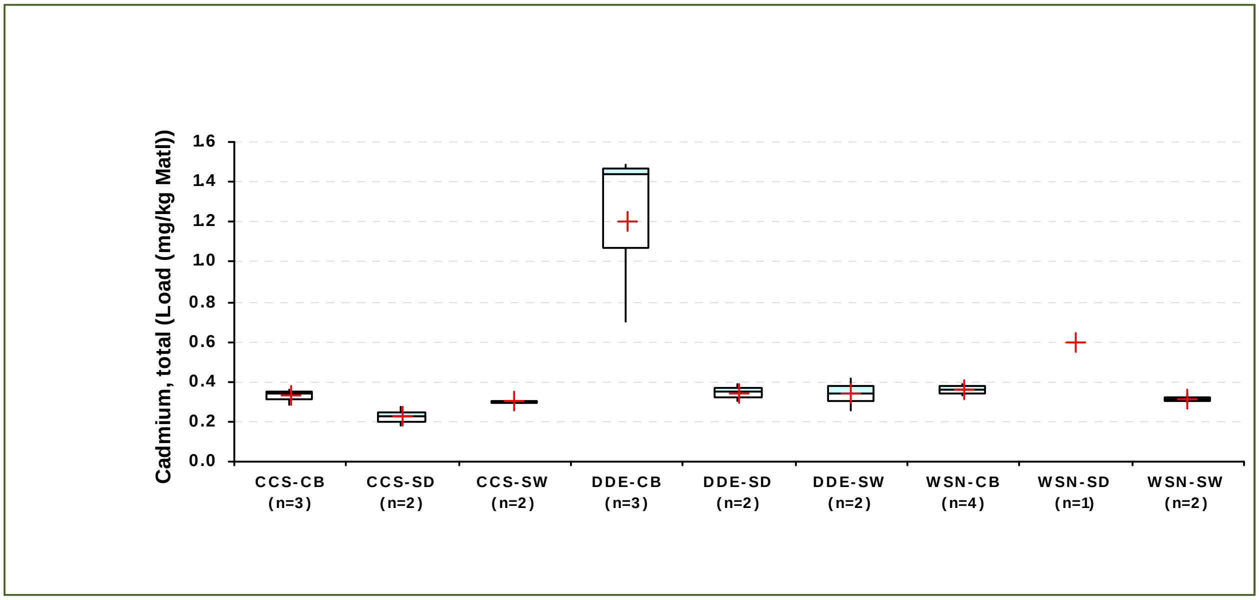

Figure 73. Box & whisker plot of cadmium load (mg/kg material) for size class coarse to medium sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

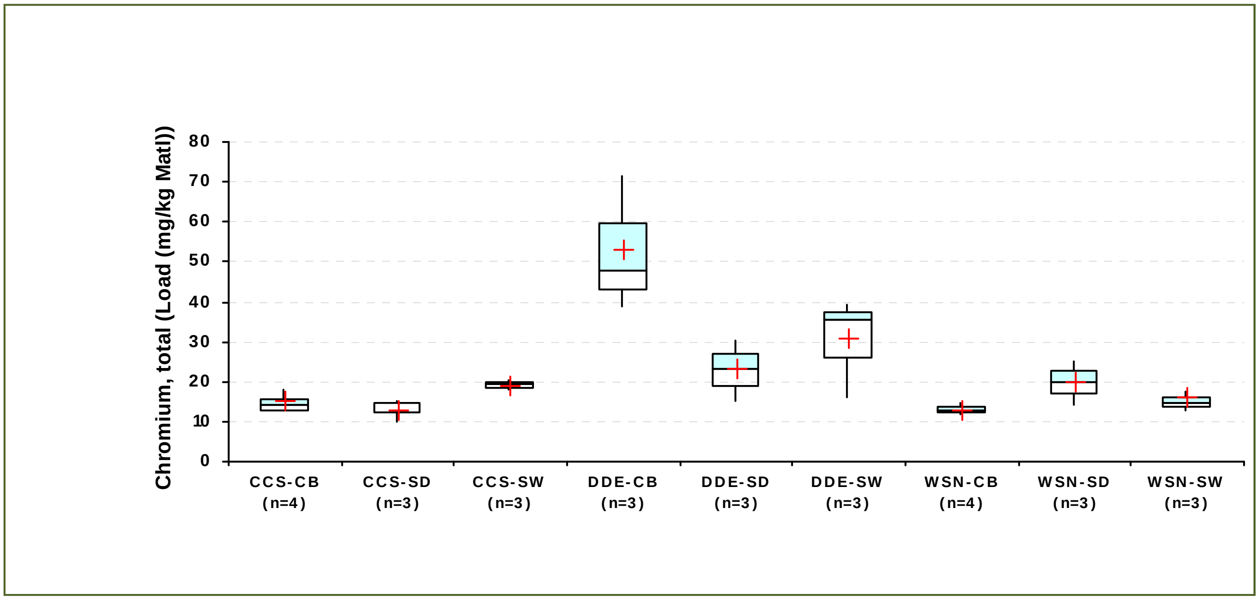

Figure 74. Box & whisker plot of chromium load (mg/kg material) for size class coarse to medium sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

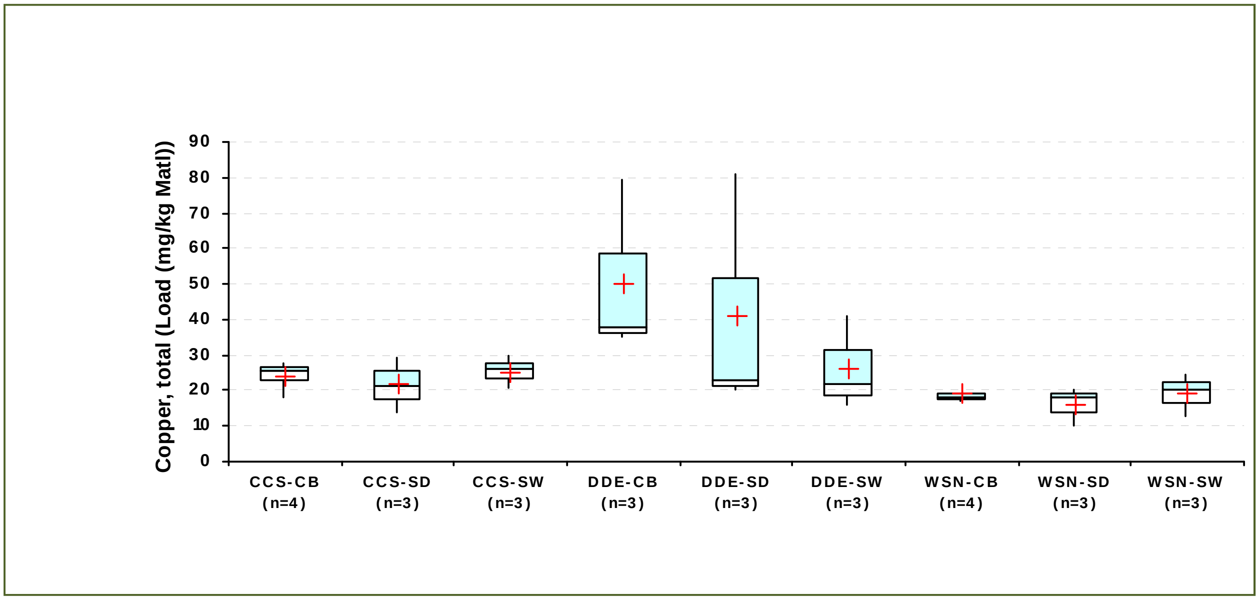

Figure 75. Box & whisker plot of copper load (mg/kg material) for size class coarse to medium sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

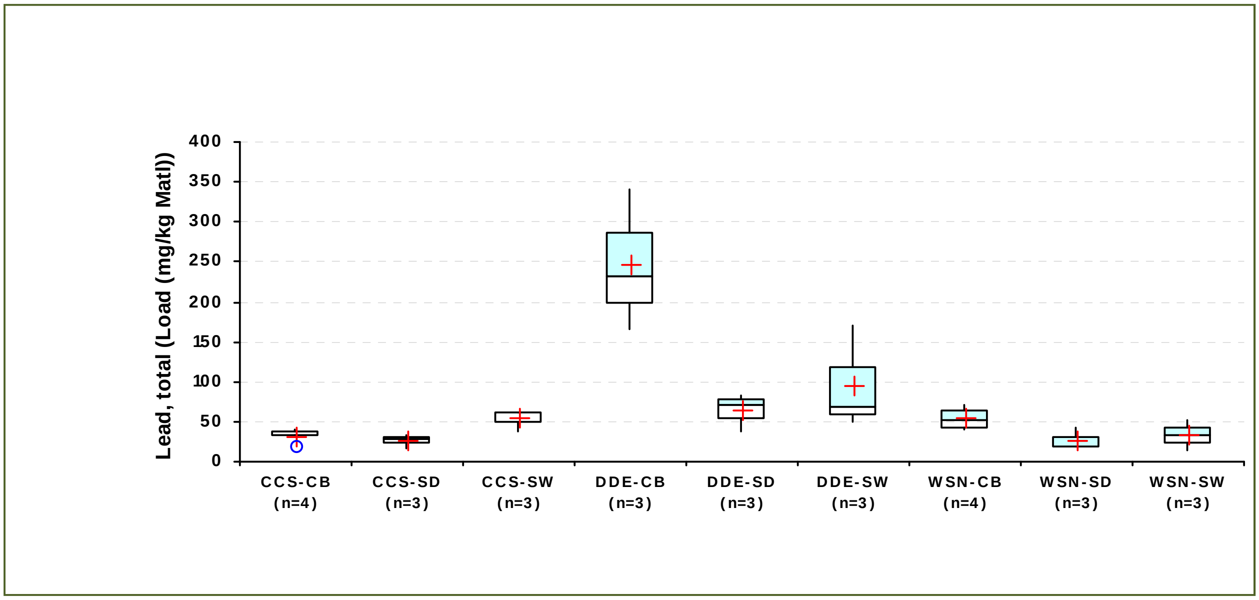

Figure 76. Box & whisker plot of lead load (mg/kg material) for size class coarse to medium sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

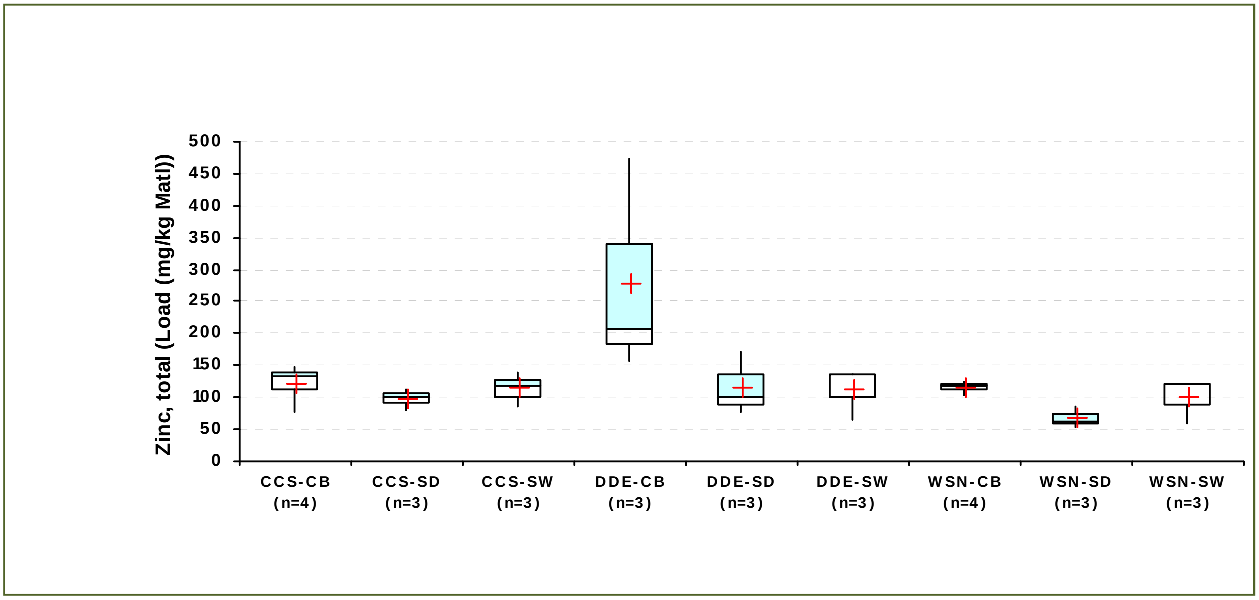

Figure 77. Box & whisker plot of zinc load (mg/kg material) for size class coarse to medium sand for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

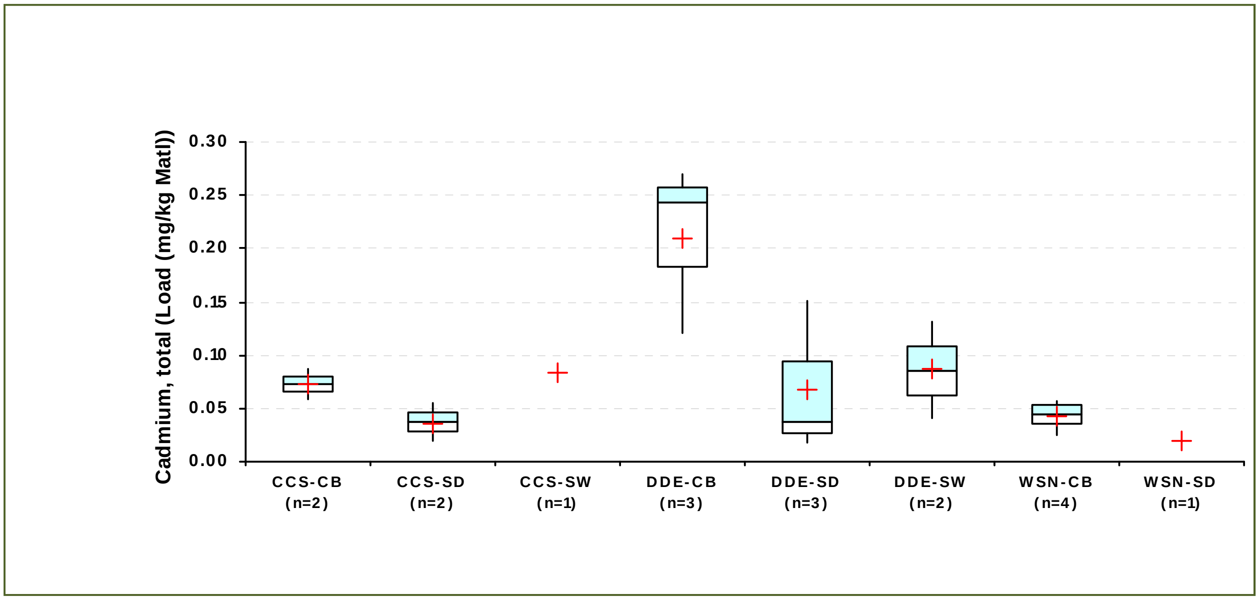

Figure 78. Box & whisker plot of cadmium load (mg/kg material) for size class gravel for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

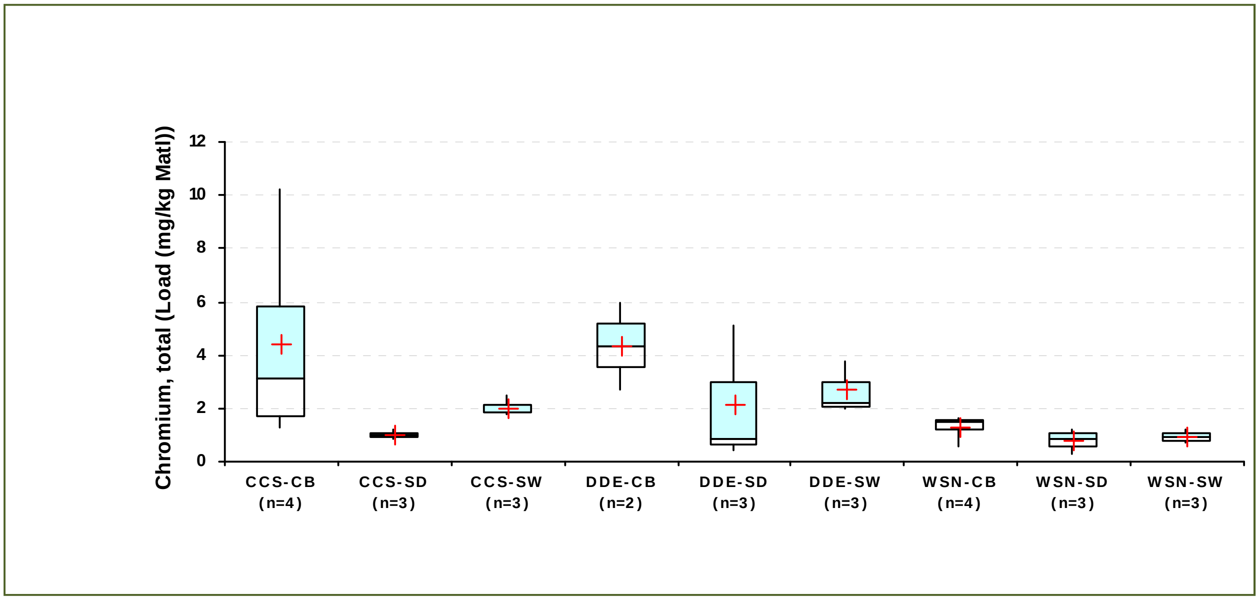

Figure 79. Box & whisker plot of chromium load (mg/kg material) for size class gravel for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

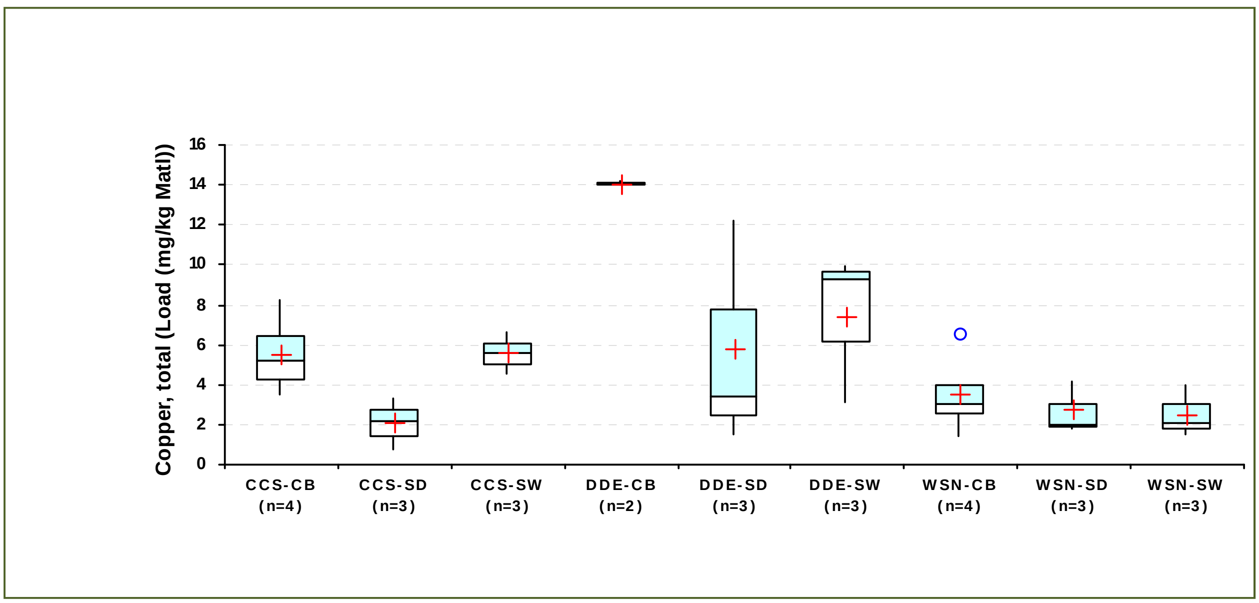

Figure 80. Box & whisker plot of copper load (mg/kg material) for size class gravel for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

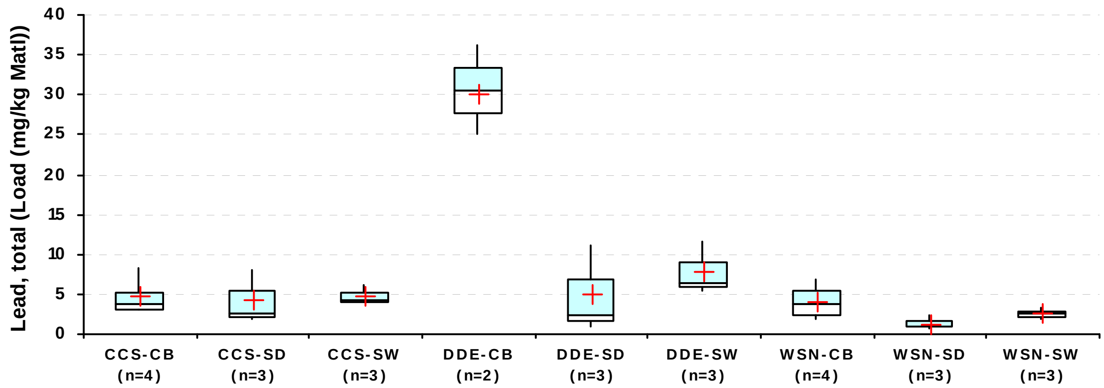

Figure 81. Box & whisker plot of lead load (mg/kg material) for size class gravel for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

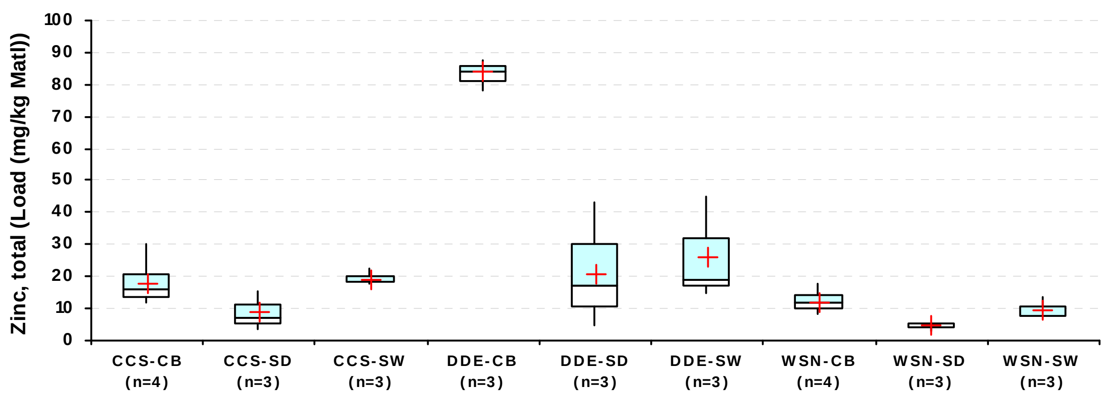

Figure 82. Box & whisker plot of zinc load (mg/kg material) for size class gravel for three sources (catch basin sediment, street dirt, and sweeper waste) and two land uses (residential sites CCS and SW and industrial site DDE).

Appendix E. Analytical Data Table – Metal Concentrations and Particle Size Distributions

Table 33. Data table - metal concentration sample results for silt/clay size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Arsenic (mg/kg)	30						10		
10/16/2006	Cadmium (mg/kg)	1.9						2.7		
10/16/2006	Chromium (mg/kg)	55						67		
10/16/2006	Copper (mg/kg)	248						203		
10/16/2006	Lead (mg/kg)	192						264		
10/16/2006	Silver (mg/kg)	0.7(R)						0.8(R)		
10/16/2006	Zinc (mg/kg)	621						737		
10/17/2006	Arsenic (mg/kg)		40	20					20	10
10/17/2006	Cadmium (mg/kg)		1.6	1.4					2.3	1.5
10/17/2006	Chromium (mg/kg)		94	61					91	60
10/17/2006	Copper (mg/kg)		191	347					151	189
10/17/2006	Lead (mg/kg)		561	216					645	198
10/17/2006	Silver (mg/kg)		0.8(R)	1.1					0.7(R)	0.9
10/17/2006	Zinc (mg/kg)		648	530					625	478
1/17/2007	Arsenic (mg/kg)	20						10		
1/17/2007	Cadmium (mg/kg)	1						2		
1/17/2007	Chromium (mg/kg)	37						51		
1/17/2007	Copper (mg/kg)	150						120		
1/17/2007	Lead (mg/kg)	112						214		
1/17/2007	Silver (mg/kg)	0.8(R)						0.7(R)		
1/17/2007	Zinc (mg/kg)	363						533		
1/30/2007	Arsenic (mg/kg)				10	10	10			
1/30/2007	Cadmium (mg/kg)				3.3	2.1	1.7			
1/30/2007	Chromium (mg/kg)				106	115	86			
1/30/2007	Copper (mg/kg)				278	232	294			
1/30/2007	Lead (mg/kg)				356	353	243			
1/30/2007	Silver (mg/kg)				1.7	1.8	0.7			
1/30/2007	Zinc (mg/kg)				705	580	344			
4/10/2007	Arsenic (mg/kg)	20	20		10	10		10	10	
4/10/2007	Cadmium (mg/kg)	1.7	1.3		3	1.8		1.8	1.3	
4/10/2007	Chromium (mg/kg)	51	49		112	98		48	71	
4/10/2007	Copper (mg/kg)	213	173		231	167		143	194	
4/10/2007	Lead (mg/kg)	179	166		360	235		194	185	
4/10/2007	Silver (mg/kg)	0.7(R)	0.9		1.4(R)	0.8		0.7(R)	0.8(R)	
4/10/2007	Zinc (mg/kg)	572	454		761	661		492	394	
4/11/2007	Arsenic (mg/kg)			10			10			10
4/11/2007	Cadmium (mg/kg)			0.9			1.8			1.2
4/11/2007	Chromium (mg/kg)			55			104			58
4/11/2007	Copper (mg/kg)			437			288			240
4/11/2007	Lead (mg/kg)			133			346			157
4/11/2007	Silver (mg/kg)			0.7(R)			2.7			0.8(R)
4/11/2007	Zinc (mg/kg)			367			463			349
6/20/2007	Arsenic (mg/kg)	20		70	10		10	10		10
6/20/2007	Cadmium (mg/kg)	1.8		1	3.9		1.7	2.3		1.4
6/20/2007	Chromium (mg/kg)	56		61	114		98	60		62

Table 33. Data table - metal concentration sample results for silt/clay size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
6/20/2007	Copper (mg/kg)	215		250	283		237	151		204
6/20/2007	Lead (mg/kg)	178		158	308		229	238		164
6/20/2007	Silver (mg/kg)	0.8(R)		0.8(R)	1.5		0.8(R)	0.8(R)		0.7(R)
6/20/2007	Zinc (mg/kg)	588		415	996		480	582		458
6/22/2007	Arsenic (mg/kg)					10			10	
6/22/2007	Cadmium (mg/kg)					2.5			1.4	
6/22/2007	Chromium (mg/kg)					116			363	
6/22/2007	Copper (mg/kg)					207			211	
6/22/2007	Lead (mg/kg)					325			171	
6/22/2007	Silver (mg/kg)					1.5			0.8	
6/22/2007	Zinc (mg/kg)					798			410	
7/2/2007	Arsenic (mg/kg)		20							
7/2/2007	Cadmium (mg/kg)		1.5							
7/2/2007	Chromium (mg/kg)		70							
7/2/2007	Copper (mg/kg)		263							
7/2/2007	Lead (mg/kg)		179							
7/2/2007	Silver (mg/kg)		0.8(R)							
7/2/2007	Zinc (mg/kg)		513							

Table 34. Data table - metal concentration sample results for fine sand size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Arsenic (mg/kg)	10						10		
10/16/2006	Cadmium (mg/kg)	1.3						2.4		
10/16/2006	Chromium (mg/kg)	37						58		
10/16/2006	Copper (mg/kg)	124						128		
10/16/2006	Lead (mg/kg)	117						211		
10/16/2006	Silver (mg/kg)	0.8(R)						0.8(R)		
10/16/2006	Zinc (mg/kg)	405						619		
10/17/2006	Arsenic (mg/kg)		10	10					10	10
10/17/2006	Cadmium (mg/kg)		0.8	0.7					1.3	1.1
10/17/2006	Chromium (mg/kg)		76	46					73	51
10/17/2006	Copper (mg/kg)		82.1	148					101	85.7
10/17/2006	Lead (mg/kg)		180	184					265	124
10/17/2006	Silver (mg/kg)		0.7(R)	0.7(R)					0.7(R)	0.7(R)
10/17/2006	Zinc (mg/kg)		356	349					381	316
1/17/2007	Arsenic (mg/kg)	10						10		
1/17/2007	Cadmium (mg/kg)	1						1.4		
1/17/2007	Chromium (mg/kg)	48						41		
1/17/2007	Copper (mg/kg)	97.2						59.2		
1/17/2007	Lead (mg/kg)	118						139		
1/17/2007	Silver (mg/kg)	0.7(R)						0.7(R)		
1/17/2007	Zinc (mg/kg)	381						355		
1/30/2007	Arsenic (mg/kg)				10	10	10			
1/30/2007	Cadmium (mg/kg)				2.3	1.3	1.1			
1/30/2007	Chromium (mg/kg)				105	97	86			

Table 34. Data table - metal concentration sample results for fine sand size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
1/30/2007	Copper (mg/kg)				148	82.6	170			
1/30/2007	Lead (mg/kg)				332	276	259			
1/30/2007	Silver (mg/kg)				0.7(R)	0.7(R)	1.9			
1/30/2007	Zinc (mg/kg)				505	378	297			
4/10/2007	Arsenic (mg/kg)	10	10		10	10		10	10	
4/10/2007	Cadmium (mg/kg)	1.3	0.9		2.6	1.1		1.2	0.7	
4/10/2007	Chromium (mg/kg)	44	42		103	82		41	48	
4/10/2007	Copper (mg/kg)	137	84		182	145		64.2	52	
4/10/2007	Lead (mg/kg)	128	98		363	192		145	88	
4/10/2007	Silver (mg/kg)	0.7(R)	0.7(R)		0.7(R)	0.7(R)		4.5	0.7(R)	
4/10/2007	Zinc (mg/kg)	432	351		616	431		335	199	
4/11/2007	Arsenic (mg/kg)			10			10			10
4/11/2007	Cadmium (mg/kg)			0.5(R)			1.1			0.5
4/11/2007	Chromium (mg/kg)			43			103			45
4/11/2007	Copper (mg/kg)			70.7			128			55.4
4/11/2007	Lead (mg/kg)			67			310			103
4/11/2007	Silver (mg/kg)			0.7(R)			0.7(R)			0.7(R)
4/11/2007	Zinc (mg/kg)			186			294			162
6/20/2007	Arsenic (mg/kg)	20		30	10		10	10		10
6/20/2007	Cadmium (mg/kg)	1.3		0.5(R)	3.3		1	1.4		0.7
6/20/2007	Chromium (mg/kg)	44		51	122		95	50		49
6/20/2007	Copper (mg/kg)	120		125	196		133	76.6		102
6/20/2007	Lead (mg/kg)	144		123	427		282	186		189
6/20/2007	Silver (mg/kg)	0.8(R)		0.7(R)	1		0.7(R)	0.8(R)		0.7(R)
6/20/2007	Zinc (mg/kg)	454		263	1050		277	391		289
6/22/2007	Arsenic (mg/kg)					10			10	
6/22/2007	Cadmium (mg/kg)					1.5			0.7	
6/22/2007	Chromium (mg/kg)					90			107	
6/22/2007	Copper (mg/kg)					112			79.4	
6/22/2007	Lead (mg/kg)					301			118	
6/22/2007	Silver (mg/kg)					0.7(R)			0.7(R)	
6/22/2007	Zinc (mg/kg)					528			217	
7/2/2007	Arsenic (mg/kg)		10							
7/2/2007	Cadmium (mg/kg)		0.5(R)							
7/2/2007	Chromium (mg/kg)		29							
7/2/2007	Copper (mg/kg)		78							
7/2/2007	Lead (mg/kg)		74							
7/2/2007	Silver (mg/kg)		0.8(R)							
7/2/2007	Zinc (mg/kg)		186							

Table 35. Data table - metal concentration sample results for coarse to medium size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Arsenic (mg/kg)	10						10		
10/16/2006	Cadmium (mg/kg)	0.7						1		
10/16/2006	Chromium (mg/kg)	30						31		
10/16/2006	Copper (mg/kg)	51.9						51.4		
10/16/2006	Lead (mg/kg)	71						114		

Table 35. Data table - metal concentration sample results for coarse to medium size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Silver (mg/kg)	0.8(R)						0.8(R)		
10/16/2006	Zinc (mg/kg)	271						321		
10/17/2006	Arsenic (mg/kg)		10	10					10	10
10/17/2006	Cadmium (mg/kg)		0.5	0.5					1.5	0.6
10/17/2006	Chromium (mg/kg)		28	31					63	27
10/17/2006	Copper (mg/kg)		38.9	50.2					46.2	35.9
10/17/2006	Lead (mg/kg)		82	64					108	60
10/17/2006	Silver (mg/kg)		0.7(R)	0.7(R)					0.7(R)	0.7(R)
10/17/2006	Zinc (mg/kg)		226	238					217	216
1/17/2007	Arsenic (mg/kg)	10						10		
1/17/2007	Cadmium (mg/kg)	0.5(R)						0.8		
1/17/2007	Chromium (mg/kg)	25						27		
1/17/2007	Copper (mg/kg)	34.3						40.4		
1/17/2007	Lead (mg/kg)	38						166		
1/17/2007	Silver (mg/kg)	0.7(R)						0.7(R)		
1/17/2007	Zinc (mg/kg)	145						242		
1/30/2007	Arsenic (mg/kg)				10	10	10			
1/30/2007	Cadmium (mg/kg)				4	0.6	0.6			
1/30/2007	Chromium (mg/kg)				127	48	38			
1/30/2007	Copper (mg/kg)				92.9	45.9	36.6			
1/30/2007	Lead (mg/kg)				611	145	116			
1/30/2007	Silver (mg/kg)				0.7(R)	0.7(R)	0.7(R)			
1/30/2007	Zinc (mg/kg)				416	349	153			
4/10/2007	Arsenic (mg/kg)	10	10		10	10		10	10	
4/10/2007	Cadmium (mg/kg)	0.5	0.5		2	0.5(R)		0.8	0.5(R)	
4/10/2007	Chromium (mg/kg)	32	28		112	38		30	41	
4/10/2007	Copper (mg/kg)	44.3	39.2		107	48.7		41.4	20.8	
4/10/2007	Lead (mg/kg)	61	61		470	94		130	38	
4/10/2007	Silver (mg/kg)	0.7(R)	0.7(R)		0.7(R)	0.7(R)		0.8(R)	0.7(R)	
4/10/2007	Zinc (mg/kg)	224	205		589	248		254	111	
4/11/2007	Arsenic (mg/kg)			10			10			10
4/11/2007	Cadmium (mg/kg)			0.5(R)			0.5(R)			0.5(R)
4/11/2007	Chromium (mg/kg)			27			73			20
4/11/2007	Copper (mg/kg)			29			39			19.8
4/11/2007	Lead (mg/kg)			87			124			23
4/11/2007	Silver (mg/kg)			0.7(R)			0.7(R)			0.7(R)
4/11/2007	Zinc (mg/kg)			120			247			89
6/20/2007	Arsenic (mg/kg)	10		10	10		10	10		10
6/20/2007	Cadmium (mg/kg)	0.7		0.6	2.8		0.8	0.8		0.5
6/20/2007	Chromium (mg/kg)	27		40	139		69	32		31
6/20/2007	Copper (mg/kg)	56.4		50.1	152		78.3	43.4		42.4
6/20/2007	Lead (mg/kg)	71		122	655		325	96		92
6/20/2007	Silver (mg/kg)	0.8(R)		0.7(R)	0.7(R)		0.7(R)	0.7(R)		0.7(R)
6/20/2007	Zinc (mg/kg)	301		235	911		260	281		204
6/22/2007	Arsenic (mg/kg)					10			10	
6/22/2007	Cadmium (mg/kg)					1.1			0.5(R)	
6/22/2007	Chromium (mg/kg)					87			31	
6/22/2007	Copper (mg/kg)					230			45.8	
6/22/2007	Lead (mg/kg)					231			39	

Table 35. Data table - metal concentration sample results for coarse to medium size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
6/22/2007	Silver (mg/kg)					0.7(R)			0.7(R)	
6/22/2007	Zinc (mg/kg)					222			139	
7/2/2007	Arsenic (mg/kg)		10							
7/2/2007	Cadmium (mg/kg)		0.5(R)							
7/2/2007	Chromium (mg/kg)		27							
7/2/2007	Copper (mg/kg)		54.3							
7/2/2007	Lead (mg/kg)		32							
7/2/2007	Silver (mg/kg)		0.7(R)							
7/2/2007	Zinc (mg/kg)		184							

Table 36. Data table - metal concentration sample results for gravel size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Arsenic (mg/kg)	10						10		
10/16/2006	Cadmium (mg/kg)	0.5(R)						0.5		
10/16/2006	Chromium (mg/kg)	14						14		
10/16/2006	Copper (mg/kg)	34.5						57.1		
10/16/2006	Lead (mg/kg)	23						45		
10/16/2006	Silver (mg/kg)	0.8(R)						0.8(R)		
10/16/2006	Zinc (mg/kg)	91						155		
10/17/2006	Arsenic (mg/kg)		10	10					10	10
10/17/2006	Cadmium (mg/kg)		0.6	0.5(R)					0.5	0.5(R)
10/17/2006	Chromium (mg/kg)		27	14					8	11
10/17/2006	Copper (mg/kg)		23.6	42.5					50.5	36.4
10/17/2006	Lead (mg/kg)		262	32					59	30
10/17/2006	Silver (mg/kg)		0.7(R)	0.8(R)					0.7(R)	0.7(R)
10/17/2006	Zinc (mg/kg)		124	137					135	124
1/17/2007	Arsenic (mg/kg)	10						10		
1/17/2007	Cadmium (mg/kg)	0.5						0.8		
1/17/2007	Chromium (mg/kg)	25						32		
1/17/2007	Copper (mg/kg)	48.2						61.4		
1/17/2007	Lead (mg/kg)	48						52		
1/17/2007	Silver (mg/kg)	0.7(R)						3.7		
1/17/2007	Zinc (mg/kg)	173						257		
1/30/2007	Arsenic (mg/kg)				10	10	10			
1/30/2007	Cadmium (mg/kg)				1.8	1.7	0.6			
1/30/2007	Chromium (mg/kg)				2050	57	17			
1/30/2007	Copper (mg/kg)				94.3	138	44.9			
1/30/2007	Lead (mg/kg)				9450	126	53			
1/30/2007	Silver (mg/kg)				0.8(R)	0.7(R)	0.8(R)			
1/30/2007	Zinc (mg/kg)				581	473	203			
4/10/2007	Arsenic (mg/kg)	10	20		10	10		10	10	
4/10/2007	Cadmium (mg/kg)	0.6	1.1		1.5	0.5		0.5	0.5(R)	
4/10/2007	Chromium (mg/kg)	13	20		33	14		12	16	
4/10/2007	Copper (mg/kg)	59.7	67.2		2150	46.7		30.1	32.9	
4/10/2007	Lead (mg/kg)	44	52		440	31		38	12	
4/10/2007	Silver (mg/kg)	0.7(R)	0.8(R)		0.8(R)	0.7(R)		0.7(R)	0.7(R)	
4/10/2007	Zinc (mg/kg)	174	311		1030	138		166	58	

Table 36. Data table - metal concentration sample results for gravel size fraction.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
4/11/2007	Arsenic (mg/kg)			10			10			10
4/11/2007	Cadmium (mg/kg)			0.7			0.5(R)			0.5(R)
4/11/2007	Chromium (mg/kg)			15			15			11
4/11/2007	Copper (mg/kg)			56.6			63.9			25.1
4/11/2007	Lead (mg/kg)			53			38			23
4/11/2007	Silver (mg/kg)			0.7(R)			0.7(R)			0.7(R)
4/11/2007	Zinc (mg/kg)			189			129			93
6/20/2007	Arsenic (mg/kg)	10		10	10		10	10		10
6/20/2007	Cadmium (mg/kg)	0.5(R)		0.5(R)	2.1		0.6	0.8		0.5(R)
6/20/2007	Chromium (mg/kg)	103		19	51		30	21		10
6/20/2007	Copper (mg/kg)	35.5		35.4	120		45.6	47.5		20
6/20/2007	Lead (mg/kg)	31		31	212		94	104		34
6/20/2007	Silver (mg/kg)	0.8(R)		0.7(R)	0.8(R)		0.7(R)	0.8(R)		0.7(R)
6/20/2007	Zinc (mg/kg)	141		138	669		220	169		105
6/22/2007	Arsenic (mg/kg)					10			10	
6/22/2007	Cadmium (mg/kg)					0.5			0.5(R)	
6/22/2007	Chromium (mg/kg)					12			12	
6/22/2007	Copper (mg/kg)					46.2			40.1	
6/22/2007	Lead (mg/kg)					32			10	
6/22/2007	Silver (mg/kg)					0.8(R)			0.8(R)	
6/22/2007	Zinc (mg/kg)					228			50	
7/2/2007	Arsenic (mg/kg)		10							
7/2/2007	Cadmium (mg/kg)		0.5(R)							
7/2/2007	Chromium (mg/kg)		11							
7/2/2007	Copper (mg/kg)		20.5							
7/2/2007	Lead (mg/kg)		18							
7/2/2007	Silver (mg/kg)		0.7(R)							
7/2/2007	Zinc (mg/kg)		67							

Table 37. Data table – particle size distribution sample results.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/16/2006	Percent retained 12500 micron sieve (%)	0.1						6.9		
10/16/2006	Percent retained 150 micron sieve (%)	8.6						12.4		
10/16/2006	Percent retained 19000 micron sieve (%)	0.1						0.5		
10/16/2006	Percent retained 2000 micron sieve (%)	17.9						9.1		
10/16/2006	Percent retained 250 micron sieve (%)	13.8						14.7		
10/16/2006	Percent retained 25K micron sieve (%)	0.1						0.1		
10/16/2006	Percent retained 32 micron (%)	7.3						11.5		
10/16/2006	Percent retained 37.5K micron sieve (%)	0.1						0.1		
10/16/2006	Percent retained 425 micron sieve (%)	16.5						14.6		
10/16/2006	Percent retained 4750 micron sieve (%)	8.8						2		
10/16/2006	Percent retained 50K micron sieve (%)	0.1						0.1		
10/16/2006	Percent retained 75 micron sieve (%)	6.8						11.8		
10/16/2006	Percent retained 75K micron sieve (%)	0.1						0.1		
10/16/2006	Percent retained 850 micron sieve (%)	16.6						14.9		
10/16/2006	Percent retained 9500 micron sieve (%)	3.6						1.6		
10/17/2006	Percent retained 12500 micron sieve (%)		0.1	3.3					0.1	0.6

Table 37. Data table – particle size distribution sample results.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
10/17/2006	Percent retained 150 micron sieve (%)		13.9	7.5					14.8	8.4
10/17/2006	Percent retained 19000 micron sieve (%)		0.1	0.1					0.2	1.7
10/17/2006	Percent retained 2000 micron sieve (%)		8.4	19.3					7.8	14.9
10/17/2006	Percent retained 250 micron sieve (%)		17.4	14.4					18.6	15.3
10/17/2006	Percent retained 25K micron sieve (%)		0.1	0.1					0.1	0.1
10/17/2006	Percent retained 32 micron (%)		15.1	2.9					10.6	4.3
10/17/2006	Percent retained 37.5K micron sieve (%)		0.1	0.1					0.1	0.1
10/17/2006	Percent retained 425 micron sieve (%)		16	19					16	19.3
10/17/2006	Percent retained 4750 micron sieve (%)		2	8.6					2.4	6.9
10/17/2006	Percent retained 50K micron sieve (%)		0.1	0.1					0.1	0.1
10/17/2006	Percent retained 75 micron sieve (%)		15	4.4					12.6	5.4
10/17/2006	Percent retained 75K micron sieve (%)		0.1	0.1					0.1	0.1
10/17/2006	Percent retained 850 micron sieve (%)		11.6	19.9					16	21.9
10/17/2006	Percent retained 9500 micron sieve (%)		0.5	0.7					0.8	1.2
1/17/2007	Percent retained 12500 micron sieve (%)	10.2	1.6	4.4				0.4	0.1	5.9
1/17/2007	Percent retained 150 micron sieve (%)	7.2	1.1	1.5				13.2	5.4	0.8
1/17/2007	Percent retained 19000 micron sieve (%)	0.3	0.1	3				0.6	0.1	0.1
1/17/2007	Percent retained 2000 micron sieve (%)	15.9	30.6	29.5				9.7	21.6	31.9
1/17/2007	Percent retained 250 micron sieve (%)	13.8	3.5	4.3				19.3	11.1	2.4
1/17/2007	Percent retained 25K micron sieve (%)	0.1	0.1	3				0.2	0.1	0.1
1/17/2007	Percent retained 32 micron (%)	4.8	0.6	0.8				10.9	0.8	0.6
1/17/2007	Percent retained 37.5K micron sieve (%)	0.1	0.1	0.1				0.1	0.1	0.1
1/17/2007	Percent retained 425 micron sieve (%)	18.2	11.3	10.9				17.9	20.3	5.8
1/17/2007	Percent retained 4750 micron sieve (%)	5.5	11.3	11.4				2.8	2.6	14.5
1/17/2007	Percent retained 50K micron sieve (%)	0.1	0.1	0.1				0.1	0.1	0.1
1/17/2007	Percent retained 75 micron sieve (%)	4.7	0.7	1				9.1	2.8	0.7
1/17/2007	Percent retained 75K micron sieve (%)	0.1	0.1	0.1				0.1	0.1	0.1
1/17/2007	Percent retained 850 micron sieve (%)	18.4	35.4	26.9				15.4	32.4	18.5
1/17/2007	Percent retained 9500 micron sieve (%)	0.8	3.9	3.2				0.6	3	18.8
1/30/2007	Percent retained 12500 micron sieve (%)				1.9	0.3	3.3			
1/30/2007	Percent retained 150 micron sieve (%)				11.6	12.1	9.3			
1/30/2007	Percent retained 19000 micron sieve (%)				2.8	0.6	7.4			
1/30/2007	Percent retained 2000 micron sieve (%)				8.7	10.7	15.5			
1/30/2007	Percent retained 250 micron sieve (%)				17.5	17.7	14.5			
1/30/2007	Percent retained 25K micron sieve (%)				5.5	0.4	2.9			
1/30/2007	Percent retained 32 micron (%)				9.1	4.3	4.9			
1/30/2007	Percent retained 37.5K micron sieve (%)				0.1	0.1	0.1			
1/30/2007	Percent retained 425 micron sieve (%)				15.9	19.3	13.8			
1/30/2007	Percent retained 4750 micron sieve (%)				3.4	6.8	6.5			
1/30/2007	Percent retained 50K micron sieve (%)				0.1	0.1	0.1			
1/30/2007	Percent retained 75 micron sieve (%)				9.5	8.2	6.6			
1/30/2007	Percent retained 75K micron sieve (%)				0.1	0.1	0.1			
1/30/2007	Percent retained 850 micron sieve (%)				13	19.1	13.6			
1/30/2007	Percent retained 9500 micron sieve (%)				1.2	0.5	1.7			
4/10/2007	Percent retained 12500 micron sieve (%)	2.4	0.1		1.4	0.5		0.3	0.1	
4/10/2007	Percent retained 150 micron sieve (%)	8	11.2		13.6	13.9		13	12.9	
4/10/2007	Percent retained 19000 micron sieve (%)	0.7	0.1		1.4	0.1		0.5	0.1	
4/10/2007	Percent retained 2000 micron sieve (%)	15.5	13.6		6.7	7.9		9.4	9.6	
4/10/2007	Percent retained 250 micron sieve (%)	15.7	19.1		18.9	17.7		20.8	21.1	

Table 37. Data table – particle size distribution sample results.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
4/10/2007	Percent retained 25K micron sieve (%)	0.2	0.1		0.1	0.2		0.3	0.7	
4/10/2007	Percent retained 32 micron (%)	5.4	3.3		12.1	12.2		6.2	4.3	
4/10/2007	Percent retained 37.5K micron sieve (%)	0.1	0.1		0.1	0.1		0.1	0.1	
4/10/2007	Percent retained 425 micron sieve (%)	20.7	22.2		16.6	16.3		20.8	21.8	
4/10/2007	Percent retained 4750 micron sieve (%)	4.9	3.9		3.7	1.6		1.9	3.5	
4/10/2007	Percent retained 50K micron sieve (%)	0.1	0.1		0.1	0.1		0.1	0.1	
4/10/2007	Percent retained 75 micron sieve (%)	5.4	7.5		12.5	13		8.4	7.7	
4/10/2007	Percent retained 75K micron sieve (%)	0.1	0.1		0.1	0.1		0.1	0.1	
4/10/2007	Percent retained 850 micron sieve (%)	19.8	18.8		11.8	16.2		16.9	17.5	
4/10/2007	Percent retained 9500 micron sieve (%)	1.3	0.4		1.3	0.6		1.5	0.8	
4/11/2007	Percent retained 12500 micron sieve (%)			0.1			4			2.1
4/11/2007	Percent retained 150 micron sieve (%)			3.9			8.1			6.4
4/11/2007	Percent retained 19000 micron sieve (%)			0.1			0.1			0.1
4/11/2007	Percent retained 2000 micron sieve (%)			25.9			14.4			16.8
4/11/2007	Percent retained 250 micron sieve (%)			10.1			14.1			13.7
4/11/2007	Percent retained 25K micron sieve (%)			0.1			0.1			0.2
4/11/2007	Percent retained 32 micron (%)			1.7			3.8			1.9
4/11/2007	Percent retained 37.5K micron sieve (%)			0.1			0.1			0.1
4/11/2007	Percent retained 425 micron sieve (%)			19.3			17.9			22.1
4/11/2007	Percent retained 4750 micron sieve (%)			8.2			8.3			4.2
4/11/2007	Percent retained 50K micron sieve (%)			0.1			0.1			0.1
4/11/2007	Percent retained 75 micron sieve (%)			2.1			5.4			3.2
4/11/2007	Percent retained 75K micron sieve (%)			0.1			0.1			0.1
4/11/2007	Percent retained 850 micron sieve (%)			25.8			22.2			28
4/11/2007	Percent retained 9500 micron sieve (%)			3			1.7			1.2
6/20/2007	Percent retained 12500 micron sieve (%)	5.6		8.9	5.8		1.3	3.2		0.8
6/20/2007	Percent retained 150 micron sieve (%)	10.1		12.1	8.8		11.5	13.9		9.2
6/20/2007	Percent retained 19000 micron sieve (%)	0.1		0.1	0.1		0.8	0.1		0.6
6/20/2007	Percent retained 2000 micron sieve (%)	10.8		11.4	15		11.8	7.4		14.3
6/20/2007	Percent retained 250 micron sieve (%)	17.8		13.8	13.6		20.4	21.4		15.8
6/20/2007	Percent retained 25K micron sieve (%)	0.1		0.1	0.1		0.1	0.1		0.1
6/20/2007	Percent retained 32 micron (%)	7		6.7	7.2		3.4	8.1		4
6/20/2007	Percent retained 37.5K micron sieve (%)	0.1		0.1	0.1		0.1	0.1		0.1
6/20/2007	Percent retained 425 micron sieve (%)	21.1		17.6	16.9		21.3	19.7		19.8
6/20/2007	Percent retained 4750 micron sieve (%)	2.2		3	4.3		4.1	2.2		3.5
6/20/2007	Percent retained 50K micron sieve (%)	0.1		0.1	0.1		0.1	0.1		0.1
6/20/2007	Percent retained 75 micron sieve (%)	7.2		4	7.5		6.4	9.2		5.9
6/20/2007	Percent retained 75K micron sieve (%)	0.1		0.1	0.1		0.1	0.1		0.1
6/20/2007	Percent retained 850 micron sieve (%)	16.7		22.1	19.8		18.9	14.3		24
6/20/2007	Percent retained 9500 micron sieve (%)	1.6		0.4	1.1		0.1	0.6		2
6/22/2007	Percent retained 12500 micron sieve (%)					1.5			2.9	
6/22/2007	Percent retained 150 micron sieve (%)					13.8			12.3	
6/22/2007	Percent retained 19000 micron sieve (%)					0.1			0.1	
6/22/2007	Percent retained 2000 micron sieve (%)					7.9			10.3	
6/22/2007	Percent retained 250 micron sieve (%)					17.2			18.7	
6/22/2007	Percent retained 25K micron sieve (%)					0.1			0.1	
6/22/2007	Percent retained 32 micron (%)					13.2			6.1	
6/22/2007	Percent retained 37.5K micron sieve (%)					0.1			0.1	
6/22/2007	Percent retained 425 micron sieve (%)					15.2			18.6	

Table 37. Data table – particle size distribution sample results.

Collect Date	Parameter	CCS-CB	CCS-SD	CCS-SW	DDE-CB	DDE-SD	DDE-SW	WSN-CB	WSN-SD	WSN-SW
6/22/2007	Percent retained 4750 micron sieve (%)					3			4.3	
6/22/2007	Percent retained 50K micron sieve (%)					0.1			0.1	
6/22/2007	Percent retained 75 micron sieve (%)					13.6			8.1	
6/22/2007	Percent retained 75K micron sieve (%)					0.1			0.1	
6/22/2007	Percent retained 850 micron sieve (%)					12.2			16	
6/22/2007	Percent retained 9500 micron sieve (%)					2.4			2.7	
7/2/2007	Percent retained 12500 micron sieve (%)		6.1							
7/2/2007	Percent retained 150 micron sieve (%)		8.8							
7/2/2007	Percent retained 19000 micron sieve (%)		0.1							
7/2/2007	Percent retained 2000 micron sieve (%)		16.7							
7/2/2007	Percent retained 250 micron sieve (%)		15							
7/2/2007	Percent retained 25K micron sieve (%)		0.1							
7/2/2007	Percent retained 32 micron (%)		4.9							
7/2/2007	Percent retained 37.5K micron sieve (%)		0.1							
7/2/2007	Percent retained 425 micron sieve (%)		18.7							
7/2/2007	Percent retained 4750 micron sieve (%)		3.3							
7/2/2007	Percent retained 50K micron sieve (%)		0.1							
7/2/2007	Percent retained 75 micron sieve (%)		6.9							
7/2/2007	Percent retained 75K micron sieve (%)		0.1							
7/2/2007	Percent retained 850 micron sieve (%)		18.9							
7/2/2007	Percent retained 9500 micron sieve (%)		0.7							