City of San Diego Targeted Aggressive Street Sweeping Pilot Study Effectiveness Assessment

Final Report
June 18, 2010

City of San Diego

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Pilot Study
Effectiveness Assessment

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EXECUTIVE SUMMARY

In 2008, the City of San Diego (City) implemented the Targeted Aggressive Street Sweeping Pilot Study within the Chollas Creek Subwatershed and the Tecolote Creek and La Jolla Shores Subwatersheds within the Mission Bay Watershed. The pilot study was designed to evaluate the effectiveness of new street sweeping technologies and different sweeping frequencies, which were anticipated to enhance removal of constituents of concern. The City's ultimate objective is to optimize the effectiveness of street sweeping operations in higher priority areas within the context of its overall watershed protection strategy. This report provides the results of the City's Targeted Aggressive Street Sweeping Pilot Study.

The study was conducted to address the following constituent reduction requirements:

- The Targeted Aggressive Street Sweeping Pilot Study is as a Phase I, Tier II pilot study identified in the City's *Strategic Plan for Watershed Activity Implementation* (Strategic Plan).
- The San Diego County Municipal Storm Water Permit (Final Order R9-2007-0001, 2007) (Permit) requires Copermittees to implement two Watershed Water Quality Activities and two Watershed Education Activities each year that result in a measurable constituent load reduction.
- The Permit requires Copermittees to prioritize municipal areas and sweep streets and parking lots based on the amount of trash and debris accumulated.
- The *Chollas Creek Dissolved Metals TMDL Implementation Plan* identifies watershed activities to be planned, implemented, and assessed during the first five years of the 20-year TMDL compliance schedule and includes the Targeted Aggressive Street Sweeping Pilot Study.
- The City is developing the *Tecolote Creek Integrated TMDL Planning Framework*, which identifies Targeted Aggressive Street Sweeping as a watershed activity to be piloted during the first phase of the implementation program.
- Implementation of Targeted Aggressive Street Sweeping in the La Jolla Shores area is part of the City's strategy for protecting Areas of Special Biological Significance (ASBS) in response to the State Water Resources Control Board (State Board) draft *Area of Special Biological Significance* (ASBS) *Special Protections* document.

The Targeted Aggressive Street Sweeping Pilot Study was designed to address the following three study questions:

1. **Which sweeping machine (i.e., mechanical, regenerative-air, or vacuum) is most effective in removing metals and other constituents of concern?**
2. **Is it more efficient and effective to aggressively sweep at a high frequency (e.g., once a week or twice a week)?**
3. **Is there a quantifiable link between aggressive street sweeping and the reduction of metals and other constituents of concern in storm water runoff?**

Relevance to Current City Efforts:
In addition to the Strategic Plan, this study compliments other City of San Diego plans, programs and cost reduction efforts that include:

- La Jolla Shores Coastal Watershed Management Plan.

- Chollas Creek Dissolved Metals TMDL Implementation Plan.
- Standard Urban Storm Water Mitigation Plan (SUSMP).
- Watershed Urban Runoff Management Programs (WURMP).
- Jurisdictional Urban Runoff Management Program (JURMP).

Results and Key Findings:

MACHINE EFFECTIVENESS	The results indicate that street sweeping provides an effective means of reducing concentrations of some constituents in storm water runoff. While machine effectiveness varied by site, the vacuum sweeper was more effective in reducing storm water constituent concentrations than the mechanical and regenerative-air sweepers. Variability in route characteristics (i.e., steeper grades and inadequate curb and gutter in La Jolla Shores) may account for the site-specific differences in machine performance. Chollas Creek Route 3J: The vacuum sweeper was more effective than the regenerative-air and mechanical sweepers in removing debris and metals from the street surface. There was marginal to no difference in performance between the regenerative-air and mechanical sweepers. La Jolla Shores: The vacuum sweeper performed marginally better than the mechanical sweeper. The vacuum sweeper only removed 20% more constituents than the mechanical sweeper from streets in La Jolla Shores.
SWEEPING FREQUENCY	Optimal load reductions were achieved by the vacuum machine at an aggressive, twice per week frequency. The mechanical sweeper was most effective at removing debris and contaminants at a less aggressive, once per week frequency. Vacuum: Sweeping frequency did not impact the vacuum sweeper's effectiveness. The vacuum sweeper collected the same amount of debris and metals per broom mile at both the once and twice per week frequencies (e.g., approximately 80 pounds of debris were removed per broom mile when sweeping was done once per week and 80 pounds of debris were removed per broom mile when sweeping was done twice per week). Mechanical: The mechanical machine was less effective, in terms of debris removed per broom mile, when sweeping twice per week versus once per week (e.g., approximately 50 pounds of debris were removed per broom mile when sweeping was done once per week, but only 30 pounds of debris were removed per broom mile when sweeping was done once per week).
WATER QUALITY	Storm water runoff concentrations of total suspended solids (TSS) and metals (copper, lead, and zinc) during the beginning of a storm event (first flush) in the vacuum-swept street were significantly less than those in the mechanically-swept and unswept streets.

1.0 INTRODUCTION

The City of San Diego (City) currently uses a fleet of mechanical street sweepers to remove trash and debris from roads and other paved surfaces. In 2008, the City implemented the Targeted Aggressive Street Sweeping Pilot Study within the Chollas Creek Subwatershed and the Tecolote Creek and La Jolla Shores Subwatersheds within the Mission Bay Watershed. The pilot study was designed to evaluate the effectiveness of new street sweeping technologies and different sweeping frequencies, which were hypothesized to enhance removal of constituents of concern. The City's ultimate objective is to optimize the effectiveness of street sweeping operations within the context of its overall watershed protection strategy. This report provides the results of the City's Targeted Aggressive Street Sweeping Pilot Study.

1.1 Regulatory Background

The City's Storm Water Department is planning and implementing best management practices (BMPs)—including the Targeted Aggressive Street Sweeping Pilot Study—on City-owned property within the Chollas Creek and Mission Bay watersheds to address the constituent reduction requirements outlined below.

1.1.1 San Diego Regional Water Quality Control Board Municipal Storm Water Permit

According to the jurisdictional requirements presented in the San Diego County Municipal Storm Water Permit (Final Order R9-2007-0001, 2007) (Permit), Copermittees are required to implement two Watershed Water Quality Activities and two Watershed Education Activities each year that result in a "significant constituent load reduction, source abatement, or other quantifiable benefits to discharge or receiving water quality in relation to the watershed's high-priority water quality issues." The Permit also requires Copermittees to prioritize municipal areas and sweep streets and parking lots based on the amount of trash and debris accumulated. The City includes the Targeted Aggressive Street Sweeping Pilot Study as a Permit activity in the Chollas Creek, Tecolote Creek, and La Jolla Shores Subwatersheds.

1.1.2 City of San Diego Total Maximum Daily Load for Chollas Creek and Tecolote Creek

On June 13, 2007, the San Diego Regional Water Quality Control Board (Regional Board) amended the Water Quality Control Plan for the San Diego Basin (Basin Plan) to incorporate TMDLs for dissolved copper, lead, and zinc for the Chollas Creek Subwatershed (Resolution No. R9-2007-0043). The City and six other dischargers named in the TMDL cooperatively wrote the *Chollas Creek Dissolved Metals TMDL Implementation Plan* (Implementation Plan). This framework indentifies watershed activities to be planned, implemented, and assessed during the first five years of the 20-year TMDL compliance schedule and includes the Targeted Aggressive Street Sweeping Pilot Study.

On February 10, 2010, the Regional Board adopted Resolution No. R9-2010-0001, which incorporated the *TMDLs for Indicator Bacteria, Project I – Twenty Beaches and Creeks in the San Diego Region, Including Tecolote Creek* into the Basin Plan. The City is developing the *Tecolote Creek Integrated TMDL Planning Framework* that, like the Chollas Creek Implementation Plan, identifies this Targeted Aggressive Street Sweeping as a watershed activity to be piloted during the first phase of the implementation program.

1.1.3 City of San Diego Strategic Plan for Watershed Activity Implementation

The *Strategic Plan for Watershed Activity Implementation* (Strategic Plan) (Weston, 2007) identifies potential Permit and TMDL watershed activities to meet constituent load reduction requirements. The document outlines an integrated, multi-constituent and adaptive management strategy for the implementation of watershed activities. Tier I source control and pollution prevention BMPs and Tier II runoff reduction and structural BMPs are emphasized during early phases of activity implementation since they are considered more efficient and cost-effective than Tier III infrastructure-intensive structural pollution reduction treatment BMPs.

The Strategic Plan identifies BMPs designed to address current and anticipated TMDL constituent reduction goals as Phase I and Phase II activities. The Targeted Aggressive Street Sweeping Pilot Study is as a Phase I, Tier II pilot study.

1.1.4 Ocean Plan Area of Special Biological Significance Exception Process, La Jolla Shores

The draft *Area of Special Biological Significance* (ASBS) *Special Protections* document indicates that defined constituent load reductions are likely to be required to meet the criteria of the California Ocean Plan or natural water quality conditions. Watershed activities will, therefore, need to better define the sources of constituents of concern, their impacts on marine ecosystems, and targeted BMP reduction strategies that address these potential impacts. Implementation of Targeted Aggressive Street Sweeping Pilot Study in the La Jolla Shores area is part of the City's strategy for ASBS protection.

1.2 Study Questions

The Targeted Aggressive Street Sweeping Pilot Study was implemented in Spring 2008. The study was designed to answer the following three study questions:

1. **Which sweeping machine (i.e., mechanical, regenerative-air, or vacuum) is most effective in removing metals and other constituents of concern?**
2. **Is it more efficient and effective to aggressively sweep at a high frequency (e.g., once a week or twice a week)?**
3. **Is there a quantifiable link between aggressive street sweeping and the reduction of metals and other constituents of concern in storm water runoff?**

By answering these questions, the City will be able to optimize the effectiveness of its street sweeping operations and begin assessing the combination of different watershed activities in the City's overall watershed protection strategy.

2.0 TARGETED AGGRESSIVE STREET SWEEPING PILOT STUDY

2.1 Study Areas

The Targeted Aggressive Street Sweeping Pilot Study was implemented in three subwatersheds within the City's jurisdiction, including Chollas Creek (Route 3J), La Jolla Shores (Route 1C and Route 103), and Tecolote Creek (Route 617, Route 618, and Route 6D). Study routes and the locations of the debris storage bins used in the pilot study are shown on Figure 2-1.

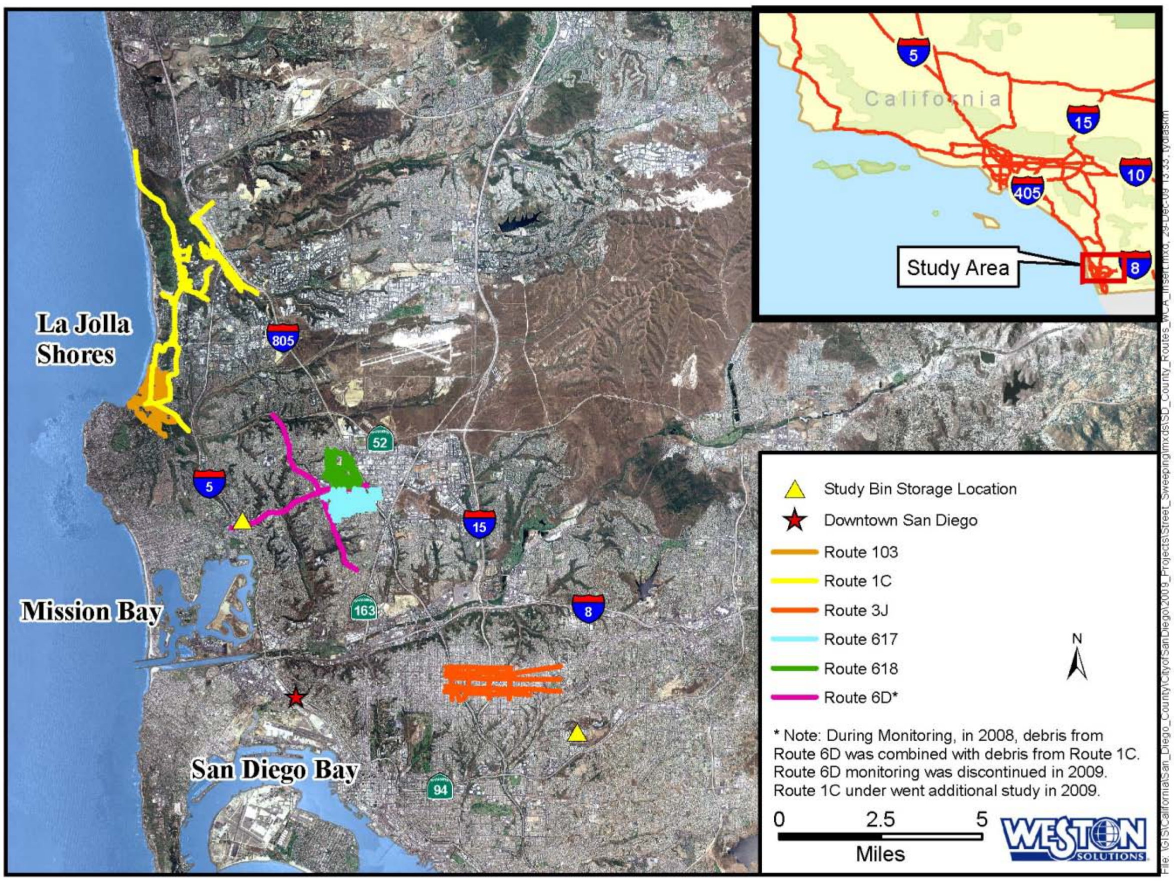

Figure 2-1. Map of Routes from the Targeted Aggressive Street Sweeping Pilot Study

2.1.1 Chollas Creek – Route 3J

The Chollas Creek Subwatershed is located northeast of downtown San Diego and empties to the eastern shoreline of San Diego Bay. The Chollas Creek street sweeping study route (i.e., Route 3J) is located in the northeastern portion of the subwatershed, within a highly urbanized, multi-family residential area. As shown on Figure 2-2, Route 3J is centered around Interstate 15, Interstate 805, and the commercial corridor of El Cajon Boulevard. This route was chosen for the pilot study because it represents a combination of three other pre-existing sweeping routes and could be used to answer all three study questions. The overall route encompasses approximately

14 linear miles. Route 3J is laid out in a relatively flat grid system with no significant changes in street grade. Portions of asphalt, curbs, and gutters along Route 3J are functional but degraded in some areas.

All debris swept from the street along Route 3J was dumped into a clearly labeled, tarped bin located at the Chollas Creek Service Yard.

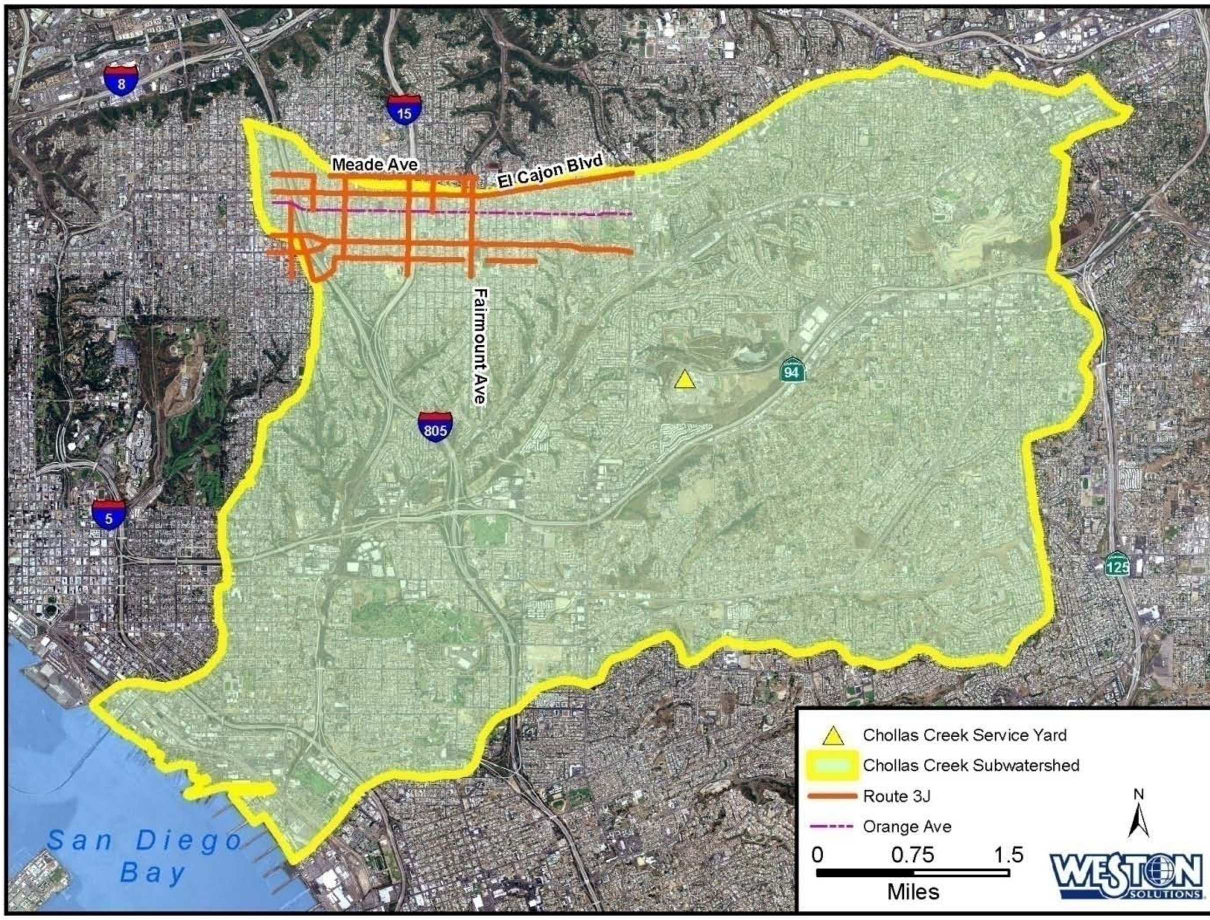

Figure 2-2. Chollas Creek Street Sweeping Study Route 3J

2.1.2 La Jolla Shores – Route 1C and Route 103

The La Jolla Shores Subwatershed is located along the Pacific coastline, west of Interstate 5 and north of downtown San Diego (Figure 2-3). The subwatershed consists of several small drainages that empty into the La Jolla Shores ASBS via ocean outfalls that connect to the City's municipal separate storm sewer system (MS4) network. There are two study routes located within the La Jolla Shores Subwatershed (i.e., the commercial study Route 1C and the mixed commercial/residential study Route 103).

Route 1C is approximately 36 miles long (Figure 2-3), but typical sweeping operations resulted in an average route length of approximately 45 miles swept with the brooms on the ground (broom miles). The route is steep in some places and includes multiple, significant changes in street grade. Torrey Pines Road, a winding, steep, major transportation corridor, constitutes a significant portion of the route. Route 1C has a well defined curb and gutter and good quality street asphalt. All debris swept from the street along Route 1C was dumped into a clearly labeled, tarped bin located at the Rose Canyon Operations Service Yard.

Route 103 is a winding route approximately 28 miles long (Figure 2-3). There are multiple changes in street grade in the eastern and southern portions of the route. Route 103 has good quality street asphalt but lacks a well-defined curb and gutter in a few locations.[1] Route details are provided on Figure 2-4. All debris swept from the street along Route 103 was dumped into a clearly labeled, tarped bin located at the Rose Canyon Operations Service Yard.

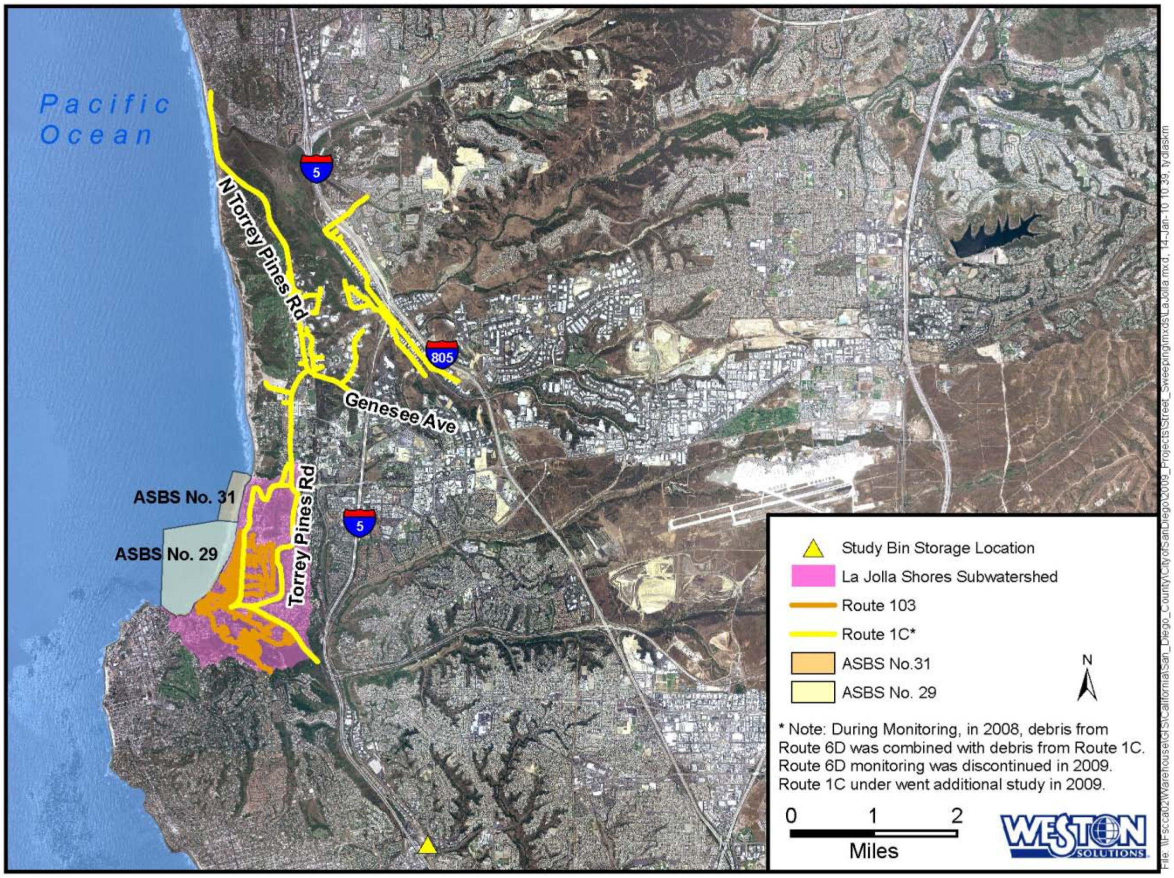

Figure 2-3. La Jolla Shores Street Sweeping Study Routes 103 and 1C

[1] There are no curbs along Roseland Drive, Torrey Pines (FTG) Boulevard, La Jolla Scenic Drive, Calle del Cielo, and swept alleys.

Figure 2-4. Close Up of Route 103 in the Commercial and Residential Areas of La Jolla Shores with Noted Route Limitations for the Vacuum and Regenerative-Air Sweepers

2.1.3 Tecolote Creek – Route 617, Route 618, and Route 6D

The Tecolote Creek Subwatershed borders Interstate 805 and is located north, northeast of Mission Bay. As shown on Figure 2-5, there are three study routes located within the Tecolote Creek Subwatershed (i.e., residential Route 617 located south of Balboa Avenue, residential Route 618 located north of Balboa Avenue, and commercial Route 6D, which includes the major corridors Genesee Avenue and Balboa Avenue).

Route 617 is approximately 28 miles long, but typical sweeping operations resulted in an average route length of approximately 20 broom miles. Route 618 is approximately 25 miles long, but typical sweeping operations resulted in an average route length of approximately 22 broom miles. Both routes are relatively flat and have street asphalt, curbs, and gutters that are in good condition. Based on similar land use, topography, and geographic location, debris swept from the street along routes 617 and 618 were considered comparable. All debris swept was dumped into a single, clearly labeled, tarped bin located at the Rose Canyon Operations Service Yard.

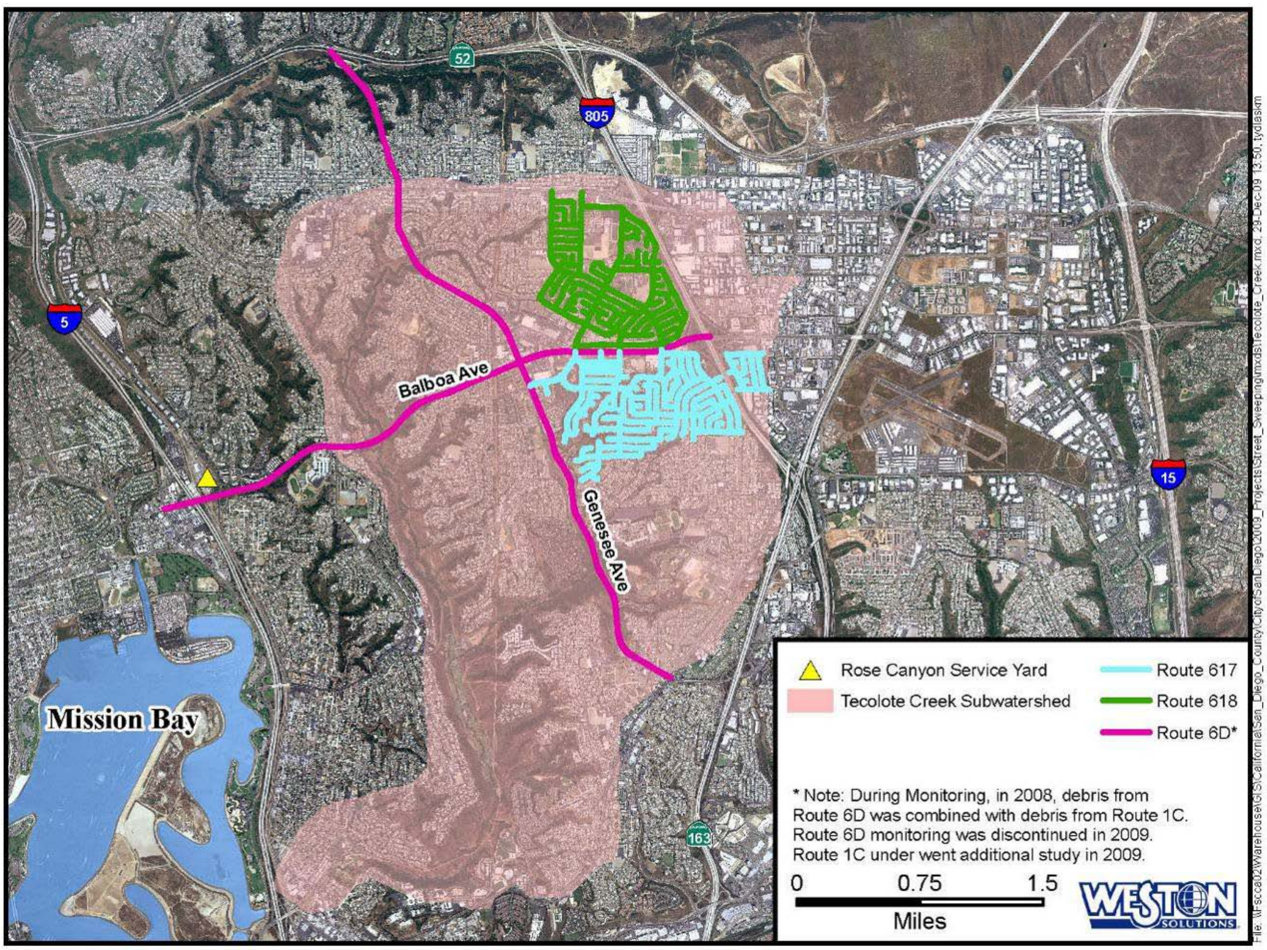

Figure 2-5. Tecolote Creek Street Sweeping Study Routes 617, 618 and 6D

Route 6D is composed of two steep, major commercial corridors in the subwatershed (i.e., Genesee Avenue and Balboa Avenue). The route is approximately 27 miles long, but typical sweeping operations resulted in an average route length of approximately 20 broom miles. Street asphalt, curbs, and gutters are in good condition.

When the Targeted Aggressive Street Sweeping Pilot Study began in 2008, debris from the La Jolla Shores commercial Route 1C was considered comparable to the Tecolote Creek commercial Route 6D because the routes have similar land uses. All debris swept from these two routes was dumped into a single, clearly labeled and tarped bin located at the Rose Canyon Operations Service Yard. In 2009, the once per week aggressive sweeping operations continued along Route 6D, but the debris was no longer monitored as part of the program. Debris from Route 6D was disposed of along with debris collected during standard mechanical sweeping operations across the City.

2.2 Sweeping Technologies

Street sweeping assessment studies indicate that new technologies (e.g., regenerative-air and vacuum street sweepers) may remove finer particulate matter from streets than standard mechanical street sweepers (Pitt, et al, 2004). Metals are known to adhere to fine-grain material, such as silts and clays (target grain size of 125 microns). Therefore, the City developed this pilot study to evaluate these newer technologies as a possible source control for removing metals and other constituents of concern. During this pilot study, the City upgraded its fleet of street sweepers to include five new mechanical sweepers, three new vacuum sweepers, and one new regenerative-air sweeper (Figure 2-6). The three technologies evaluated during the Targeted Aggressive Street Sweeping Pilot Study are detailed in Table 2-1.

Figure 2-6. City of San Diego's Sweeper Fleet of Mechanical Sweepers (left), Regenerative-Air and Vacuum Sweepers (right)

Table 2-1. Street Sweeping Technologies Assessed for the Targeted Aggressive Sweeping Pilot Study

Street Sweeping Machine	Machine Specifications
MECHANICAL STREET SWEEPER  	Modern mechanical street sweepers are equipped with water tanks and sprayers used to loosen particles and reduce dust. Mechanical brooms gather debris underneath the sweeper and the vacuum system pumps debris into the hopper (storage receptacle). BRAND: Johnston 4000 COST: $193,000 CAPACTIY: 6 cubic yards Number in Fleet: 24
REGENERATIVE-AIR SWEEPER 	Regenerative-air street sweepers use forced air to create a swirling knifing effect inside a contained area underneath the machine (sweeping head). The swirling knifing effect generates negative pressure on the suction side of the sweeping head, which transfers debris into the hopper. The debris-laden air is then cleaned and reused to start the process anew. Literature has shown these machines to be significantly better at removing total solids, nutrients, and metals than standard mechanical sweepers. BRAND: Schwartz A7000 COST: $165,000 CAPACTIY: 8 cubic yards Number in Fleet: 1
VACUUM SWEEPER  	Vacuum-assisted street sweepers use a high-powered vacuum to suction debris directly from the road surface and transfer the debris into the hopper. Literature has shown these machines to be significantly better at removing total solids, nutrients, and metals than standard mechanical sweepers. BRAND: Elgin Whirlwind COST: $203,000 CAPACTIY: 8 cubic yards Number in Fleet: 3* *The City originally procured one Elgin vacuum sweeper for the Targeted Aggressive Sweeping Pilot Study. Two additional vacuum sweepers were purchased in fiscal year (FY) 2009 based on preliminary results and considerations from FY2008.

2.3 Machine Effectiveness Assessment

The Machine Effectiveness Assessment was designed to address Study Question No. 1, as follows:

> **Which sweeping machine (i.e., mechanical, regenerative-air, or vacuum) is most effective in removing metals and other constituents of concern?**

2.3.1 Study Design

In 2008, a machine effectiveness assessment was implemented in the Chollas Creek Subwatershed (i.e., Route 3J). The assessment targeted debris swept during dry weather conditions to evaluate the effectiveness of the three types of machines (i.e., mechanical, regenerative-air, and vacuum sweepers) in removing debris and constituents from the street. At the same time, monitoring was also implemented in the La Jolla Shores and Tecolote Creek Subwatersheds to compare machine performance across different land uses and drainage areas.

The preliminary debris weight and metals results from Route 3J identified the vacuum sweeper as the optimal performing machine (Weston, 2008a). However, the debris weight data for La Jolla Shores (i.e., Route 1C and Route 103) and feedback from the sweeper operators had identified possible route-specific limitations for the vacuum sweeper. Additional targeted monitoring was implemented in La Jolla Shores (i.e., Route 1C) in 2009. The 2009 machine effectiveness assessment was designed to compare the optimal performing machine (vacuum sweeper) with the City's standard equipment (mechanical sweeper). The purpose of the 2009 assessment was to confirm the findings of the 2008 Route 3J machine assessment and identify route-specific limitations which could impact sweeper performance. The parameters of the machine effectiveness assessments are summarized in Table 2-2.

Table 2-2. Machine Effectiveness Assessment Study Design Summary

Study Question	2008		2009
No. 1 Machine Assessment	CHOLLAS CREEK; Mechanical, regenerative-air, and vacuum.	LA JOLLA SHORES, TECOLOTE CREEK;* Land use and drainage area.	LA JOLLA SHORES; Mechanical and vacuum; Route specific limitations for machine performance.

* The preliminary data from 2008 did not discern a significant difference in performance between the regenerative-air and mechanical sweepers. Additional debris weight data was collected in the Tecolote Creek Subwatershed to provide a large dataset for statistical assessment. No additional water quality monitoring was conducted.

Machine effectiveness was evaluated according to the following three parameters on a weekly basis:

- Removal of trash and debris (pounds of debris per broom mile swept).
- Removal of constituents of concern (pounds of constituent per broom mile swept).
- Debris particle size.

Weekly sweeping operations with specified machines were completed per the overall pilot study schedule.[2] On Friday morning, after sweeping operations were completed for the week, routes were evaluated for completeness based on the number of miles swept along the route with brooms in contact with the road surface (i.e., broom miles). Daily reports submitted by the machine operator were evaluated for completeness to assure comparability between sweeping machines. If the number of broom miles reported on the Daily Report was greater than or equal to 80% of the route length, the route was considered complete and appropriate for debris sampling. An example Daily Report is provided in Appendix A. Once a route was considered complete and appropriate for sampling, a Field Scientist collected and composited route-specific grab samples from the appropriate study bin(s) (Subsection 2.3.2). The following day, City staff transported project bins to the Miramar Transfer Station for weighing and disposal. Debris samples were placed on ice upon collection and were transported to the appropriate analytical laboratory for analyses. Debris samples were analyzed for grain size and sediment chemistry. Three debris samples were collected and analyzed for each machine at equivalent sweeping frequencies.

2.3.2 Monitoring Protocols

Study Bins

All debris swept along the designated study routes was separated from debris swept during standard City operations. Debris swept as part of this pilot study was dumped into dedicated roll-off bins[3]. The time constraints of standard sweeping operations made it infeasible to secure swept debris inside the bins with a solid lid and lock. Instead, study bins were equipped with a retractable tarp to protect swept debris from moisture (e.g., rain, fog and mist), aerial deposition, and illegal dumping (Figure 2-7). The potential for illegal dumping was further minimized by storing study bins in secure City facilities (Rose Canyon Operations Service Yard or Chollas Creek Service Yard) and by equipping bins with educational signage regarding the pilot study. There were a few instances of illegal dumping in Spring 2008; dumped items were noted in field forms and were removed prior to transport to the Miramar Transfer Station (Figure 2-8). Dumped items included tires, paint, boxes, wood, and furniture (e.g., a sofa). Illegally dumped items were easily identified and at no time compromised the sample.

[2] A master schedule for the pilot study was outlined in the *Street Sweeping BMP Effectiveness Monitoring Final Work Plan* (Weston, 2008b) and amended in the *Street Sweeping BMP Effectiveness and Trash Segregation Device Monitoring Program Final Work Plan* (Weston, 2009c). This schedule identified a weekly sweeping assignment for each machine along each of the study routes and corresponding monitoring activities. The master schedule was maintained to the maximum extent practicable, but was modified and re-projected on a weekly basis based on the serviceability of sweepers, standard City procedures (no sweeping on holidays or 5th weeks), weather, etc.

[3] Lockable, upright dumpsters could not be used due to the machine dumping configurations and the large volume of debris collected. Furthermore, the pilot study was designed to emulate standard sweeping operations and dumpsters are not representative of standard debris disposal procedures and equipment.

Figure 2-7. Roll-Off Bins were Transported to Miramar Transfer Station on Trucks (left) Bins were Fitted with Retractable Tarps, which Minimized Human and Environmental Influence on Swept Debris (right)

Figure 2-8. Typical Debris Composition (left) and Items Illegally Dumped and Removed from Study Bins (right)

Modifications in the City's debris transfer facilities were necessary to accommodate the regenerative-air and vacuum sweepers. The regenerative-air and vacuum sweepers have side dumping hoppers with a lower maximum dumping height than the mechanical sweepers, which have rear dumping hoppers. The standard roll-off bins purchased for the pilot study were too tall for the new machines. The following two solutions were developed (Figure 2-9):

1) Three large concrete ramps were constructed in the Chollas Creek Service Yard to accommodate the new machines. The ramps were approximately 10 ft long and were placed adjacent to the study bin(s) dedicated for the Chollas Creek route(s). The Sweeper Operator positioned the sweeper on the ramp to dump into the appropriate study bin.
2) Due to space constraints, ramps could not be built at the Rose Canyon Operations Service Yard. The sides of the bins had to be structurally modified and lowered. Fabrication at the City's metal shop required between one to three weeks per study

bin. Once a bin was modified, it was re-weighed at the Miramar Transfer Station prior to inclusion in the study.

Figure 2-9. Concrete Ramps at Chollas Creek Service Yard (left) and Bin Structurally Modified to Include a Side Gate at Rose Canyon Operations Service Yard (right)

The bin identification, storage location, associated sweeping route, and type of bin modification to accommodate the new street sweepers is presented in Table 2-3.

Table 2-3. Study Bin Names and Sweeping Routes Summary

Bin ID	Storage Location	Sweeping Route		Type of Bin Modification
		2008	2009	
CC-1 (a)	Chollas Creek Service Yard	3J	3J	Ramp
MB-1	Rose Canyon Operations Service Yard	103	103	Structural modification
MB-2	Rose Canyon Operations Service Yard	617, 618	617, 618	Structural modification
MB-3	Rose Canyon Operations Service Yard	1C, 6D	1C	Structural modification

(a) During the 2008 monitoring program, two additional bins (Orange-East and Orange-West) were dedicated to the Chollas Creek study route for the sweeping frequency assessment. Orange Avenue was later removed from the Chollas Creek Program.

Debris Sampling Protocol

A Field Scientist collected and composited route-specific grab samples on Fridays, after a route had been designated complete. Similarly sized, representative grab samples were collected with a decontaminated, stainless-steel shovel from five locations in the study bin (i.e., the four corners of the debris pile and the middle of the pile). The five samples were placed into a single heavy-duty plastic storage bag, homogenized in the bag, and stored on ice. During sampling, the Field Scientist wore a face mask, steel toe wading boots, and powder-free nitrile gloves. After the debris had been collected, the Field Scientist completed the Debris Monitoring Field Form (Appendix B). The form was designed to characterize the trash and debris (including physical characteristics), evidence of standing water, and an estimate of debris volume. Representative photographs were taken during each sampling event. Typical field sampling protocols are shown on Figure 2-10.

Figure 2-10. Debris Sampling Protocols for Pilot Study

All samples were kept under chain of custody throughout the collection, transport, and analytical process. Samples were considered to be in custody if they were (1) in the custodian's possession or view, (2) retained in a secured place (under lock) with restricted access, or (3) placed in a container and secured with an official seal such that the sample could not be reached without breaking the seal. Each person who had custody of the samples signed the form and ensured that the samples were not left unattended unless properly secured. Completed chain-of-custody forms were placed in a plastic envelope and were kept inside the cooler containing the samples. Upon delivery to the analytical laboratory, the chain-of-custody form was signed by the person receiving the samples. A standard chain-of-custody form is provided in Appendix C.

<u>Debris Weighing and Disposal Protocol</u>
Study bins were transported to Miramar Transfer Station to be weighed and emptied over weekends. Debris weight information is presented in the form of a Dump Ticket, which the transfer station uses to bill the City for debris disposal (Appendix D). This pilot study used final debris weight (net weight) in pounds. Bin-specific dump tickets and route-specific daily reports were used to determine pounds of debris removed per broom mile swept for each route for each week.

2.3.3 Analysis

Toxic Characteristic Leaching Procedure

The City's Environmental Services Division required all swept debris collected for the pilot study to undergo a Toxic Characteristic Leaching Procedure (TCLP) analysis prior to disposal of debris in the Miramar Landfill. No disposal was permitted until samples swept on each study route, for each type of machine, were analyzed and were shown to be below required metals concentrations. These analyses were completed in 2008. Debris samples collected from all three types of street sweepers were deemed non-hazardous and therefore eligible for disposal in the Miramar Landfill.

Grain-Size Analysis

When the composite debris sample had been received in the laboratory, approximately 500 grams of debris were removed and sieved using a decontaminated stainless-steel bucket and No. 4 sieve. The original sample was frozen, and the sieved subsamples were placed in plastic bags and shipped on ice to Core Laboratories in Bakersfield, California, where they were analyzed for grain size using the laser particle size diffraction technique (ASTM D422/D4464M).

Debris Chemistry Analysis

Pre-sieved debris subsamples were also sent on ice to CRG Marine Laboratories in Torrance, California and analyzed for total metals, synthetic pyrethroids, nitrate, nitrite, ammonia, total Kjeldahl nitrogen (TKN) and phosphorus (Table 2-4). Samples were collected and transferred to the laboratory following standard chain-of-custody practices. Analytical laboratory reports underwent a thorough quality assessment / quality control evaluation prior to analysis and reporting.

Table 2-4. Analytical Methods for Collected Dry Weather Debris Samples

Analyte	Method	MDL	RL	Units	Holding Time
Total and Dissolved Metals					
Aluminum (Al)	EPA 200.8(m)	5.0	10.0	µg/L	Two weeks
Antimony (Sb)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Arsenic (As)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Barium (Ba)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Beryllium (Be)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Cadmium (Cd)	EPA 200.8(m)	0.2	0.4	µg/L	Two weeks
Chromium (Cr)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Cobalt (Co)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Copper (Cu)	EPA 200.8(m)	0.4	0.8	µg/L	Two weeks
Iron (Fe)	EPA 200.8(m)	5.0	10.0	µg/L	Two weeks
Lead (Pb)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Manganese (Mn)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Molybdenum (Mo)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Nickel (Ni)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Selenium (Se)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Silver (Ag)	EPA 200.8(m)	0.5	1	µg/L	Two weeks
Strontium (Sr)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Thallium (Tl)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Tin (Sn)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Titanium (Ti)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Vanadium (V)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Zinc (Zn)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Vanadium (V)	EPA 200.8(m)	0.2	0.5	µg/L	Two weeks
Zinc (Zn)	EPA 200.8(m)	0.1	0.5	µg/L	Two weeks
Synthetic Pyrethroid Pesticides in Sample Extract Analysis by NCI-GCMS					
Allethrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Bifenthrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Cyfluthrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Cypermethrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Danitol	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Deltamethrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
L-cyhalothrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Permethrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
Prallethrin	NCI-GCMS	0.5	2.0	ng/L	Two weeks
General Chemistry					
Ammonia in sediment determination	SM 4500-NH3 F	0.01	0.05	mg/L	Two weeks
Nitrate in sediment determination	EPA 300.1	0.01	0.05	mg/L	Two weeks
Nitrite in sediment determination	EPA 300.1	0.01	0.05	mg/L	Two weeks
TKN in sediment determination	EPA 351.3	0.455	0.50	mg/L	Two weeks
Total phosphorus in sediment determination	SM 4500-P C	0.016	0.05	mg/L	Two weeks

2.4 Sweeping Frequency Assessment

The Sweeping Frequency Assessment was designed to address Study Question No. 2, as follows:

> **Is it more efficient and effective to aggressively sweep at a high frequency (e.g., once a week or twice a week)?**

2.4.1 Study Design

Residential streets in the City are typically swept either once per month, or once every other month, while commercial streets may be swept as frequently as once per week. A sweeping frequency assessment targeting debris swept during dry weather conditions was implemented in the Chollas Creek Subwatershed to determine the effectiveness of constituent removal at two aggressive sweeping frequencies (i.e., once per week vs. twice per week). When compared to standard sweeping procedures, the piloted aggressive sweeping frequencies increased sweeping 4x to 16x fold in residential areas, and doubled the frequency of sweeping in commercial areas.

The Chollas Creek, La Jolla Shores, and Tecolote Creek routes were swept at different frequencies, and the corresponding debris weights and constituent loads were used to assess effectiveness. The study design is summarized in Table 2-5.

Table 2-5. Sweeping Frequency Assessment Study Design

Study Question	2008 (LOCATION(S); comparison; sweeping frequency)	2009 (LOCATION(S); comparison; sweeping frequency)
No. 2 Sweeping Frequency Assessment	CHOLLAS CREEK; Mechanical versus vacuum; Twice per week	CHOLLAS CREEK; Once per week frequency with the mechanical and vacuum
	LA JOLLA SHORES* Once per week frequency with the mechanical and vacuum	
	TECOLOTE CREEK; * Once per week frequency with the mechanical and regenerative-air	

* Due to a limited number of vacuum and regenerative-air sweepers available during this pilot study, the machine and frequency assessments were focused on specific machines in the La Jolla Shores and Tecolote Creek Subwatersheds.

In 2008, targeted aggressive street sweeping was implemented along Route 3J in the Chollas Creek Subwatershed and along a 2.5 mile stretch of Orange Avenue between Illinois Street to the west and 54th Street to the east. The pilot study was originally designed to assess machine effectiveness along the longer Route 3J and sweeping frequency along Orange Avenue. Sweeping was implemented at an aggressive frequency (e.g., twice per week) along Route 3J and the western portion of Orange Avenue (approximately 1.4 miles between Fairmount Avenue and Illinois Street). “No Parking” signs were posted along the study route to ensure that the street sweepers would have access to the curb and gutter, the area with the greatest accumulation of debris.[4] Route 3J and Orange-West were "posted" such that sweeping on each side of the street would fall on alternating days (e.g., Mondays and Wednesdays on the south side of the street and Tuesdays and Thursdays on the north side of the street). Once per week sweeping was implemented along the eastern portion of Orange Avenue (approximately 1.4 miles between Fairmount Avenue and 54th Street). Orange-East was posted for sweeping on Mondays and Tuesdays. All debris swept along Route 3J, Orange-West, and Orange-East was dumped into three clearly labeled, tarped bins located at the Chollas Creek Service Yard. As the sweeping frequency assessment study progressed, results from Orange Avenue were highly inconsistent. The Orange-West and Orange-east portions of the study were terminated due to the two following issues:

- The Orange-West and Orange-East routes were too short to collect sufficient debris for a statistical comparison of debris weights.
- Sweeping was applied inconsistently and the debris data were not representative of the frequency assessment identified in the study design.

These issues provided valuable insight regarding operator training, inter-department and intra-department communication, and the existence of a diminishing return in terms of machine performance compared to route length. This last point was based on a qualitative assessment of the frequency and duration of machine breakdowns for the longer routes.

To answer the sweeping frequency assessment study question, the City modified the study design to target Route 3J. Monitoring data had been collected from this route for all three street sweepers operating at an aggressive sweeping frequency (i.e., twice per week). Preliminary results indicated that the vacuum sweeper out-performed the regenerative-air sweeper in debris and constituent removal.

Starting April 13, 2009, sweeping along Route 3J and Orange-West was reduced to a frequency of once per week. Due to time constraints of the program, the low-frequency sweeping assessment schedule was compressed. Three weeks of sweeping and sampling was implemented along Route 3J for the mechanical sweeper, and a similar three week program was implemented for the vacuum sweeper.[5] Thus, the modified study design only evaluated frequency of the standard sweeper and the optimally functioning sweeper (i.e., vacuum). A summary of the modified sweeping frequency assessment is presented on Table 2-5.

The sweeping frequency assessment used the same monitoring protocols and analyses as the machine effectiveness assessment (subsections 2.2.3 and 2.2.4).

2.5 Water Quality Assessment

The Water Quality Assessment was designed to address Study Question No. 3, as follows:

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[4] Signage already existed along portions of Route 3J, but existing signage was changed to reflect the change in sweeping frequency. In the Tecolote and La Jolla Shores Subwatersheds, the pilot study was implemented along previously un-posted routes.

[5] This idealized schedule was maintained to the maximum extent practicable (Weston, 2008b, Weston 2009c). The schedule of sweeping and sampling was modified based on the serviceability of sweepers, City sweeping procedures (no sweeping on holidays or 5th weeks), weather, etc.

Is there a quantifiable link between aggressive street sweeping and the reduction of metals and other constituents of concern in storm water runoff?

2.5.1 Study Design

Constituent removal from each subwatershed through street sweeping can be determined using the results from the machine effectiveness assessment and the sweeping frequency assessment. However, assessing debris removed from the street only quantifies load reductions from sediment-associated constituents. A water quality assessment was designed for the Chollas Creek Subwatershed to determine if the removal of sediment-associated constituents through street sweeping results in direct improvements to water quality.

The original water quality assessment was intended to isolate the impact of street sweeping on water quality by simulating a typical rainfall event over a given area of swept street and then evaluating water quality for all three machines at the aggressive sweeping frequencies. While designing the simulation device, it was determined that flooding of the street to simulate rainfall would not provide the desired output. Not only would the simulation machine produce inadequate volumes of water for analyses and/or potentially introduce constituents to the system, the street surface area necessary for measurable constituent quantities in the wash off was too large (i.e., at least one city block) for a scientifically controllable experiment. The simulated rain event assessment was replaced with storm monitoring during the 2009–2010 Wet Weather Monitoring Season, and a laboratory analysis (EPA Method 1312, Synthetic Precipitation Leaching Procedure, SPLP) was used to evaluate the potential for metals to leach from swept street debris into water.

2.5.2 Water Quality Monitoring Protocols

To evaluate the impact of street sweeping on water quality, monitoring was conducted during three storm events at each of the following three locations in the Chollas Creek Subwatershed:

- Meade Avenue West of Interstate 15 – A section of street swept by a mechanical sweeper.
- Meade Avenue East of Interstate 15 – A section of street swept by the vacuum-assisted sweeper.
- McClintock Street – A residential side-street adjoining Meade Avenue, west of Interstate 15, swept with a mechanical sweeper on the City's standard residential sweeping frequency of once every two months (identified as "unswept" in this report). Unlike Meave Avenue, McClintock Street is within an "un-posted" route, which means the street sweeper navigates around parked vehicles in a process known as free-sweeping. This route is swept on even numbered months (i.e., February, April, June, August, October, and December).

Meade Avenue was selected based on a field reconnaissance of Route 3J. Meade Avenue represented the most uniform study area, consisting of three areas with similar residential land uses, consistent higher-quality asphalt, continuous sections of curbs and gutters, and a relatively flat grade. Meade Avenue was selected rather than El Cajon Boulevard and University Avenue to minimize point source inputs from automotive and other commercial facilities. For this portion of the study, Meade Avenue was divided into two, three block subdrainage areas with comparable land uses, vehicular traffic, and number of side alleys (three alleys per each section of Meade Avenue). Meade Avenue is also adjacent to “unswept” side streets (i.e. City standard once every-other-month sweeping with mechanical sweepers), which had no potential to receive runoff from Route 3J. The three wet weather monitoring locations are shown on Figure 2-11.

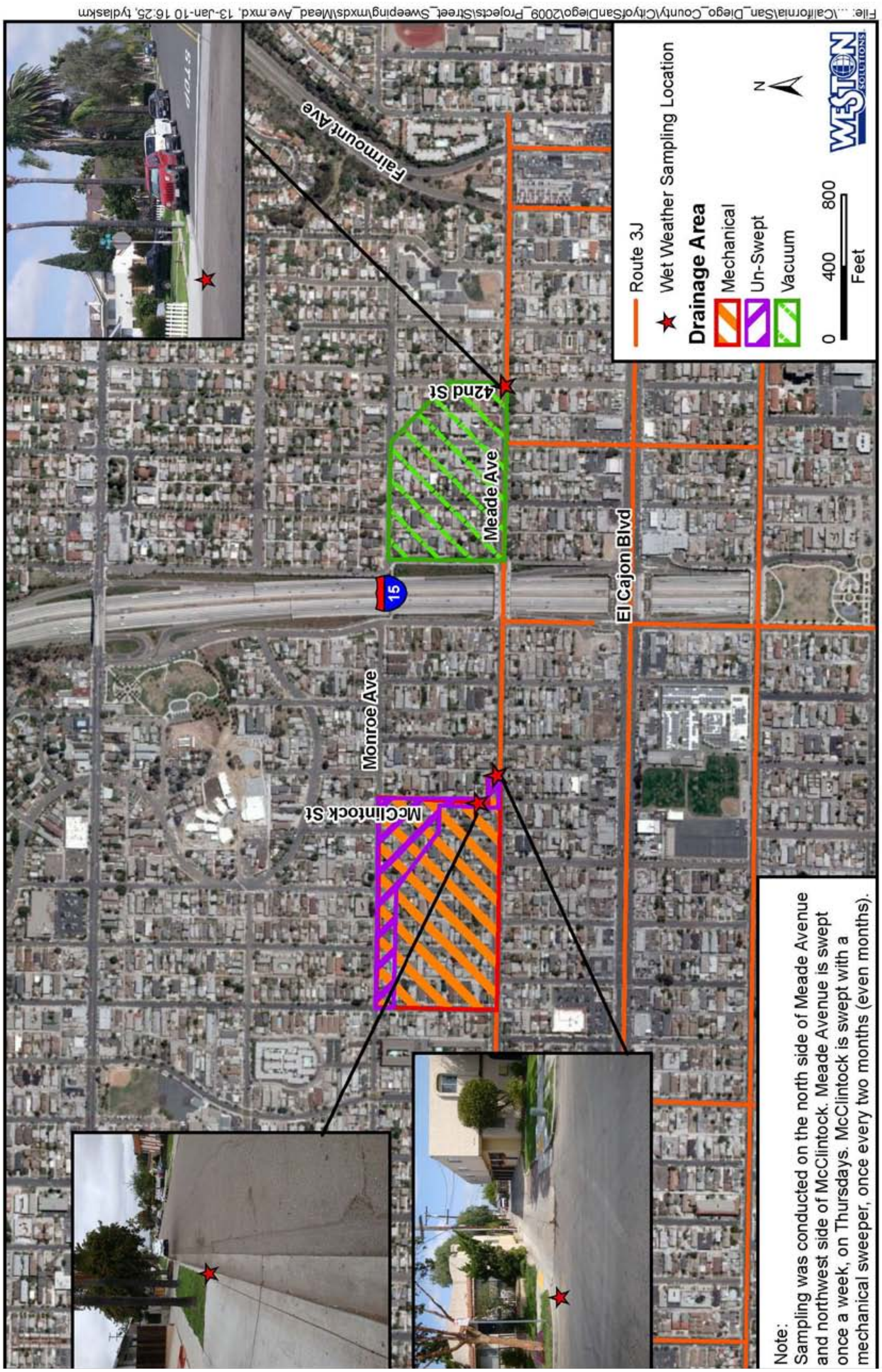

Figure 2-11. Wet Weather Monitoring Locations along Meade Avenue

Storm events were considered viable for monitoring if they were forecast for greater than 0.25 inches of rainfall at a greater than 70% probability, and were preceded by 48 hours or more of dry weather. Sampling was conducted if the north side of Meade Avenue. This portion of the route was swept with appropriate sweeper (mechanical to the west, vacuum to the east) for at least three weeks prior to a storm event.

During wet weather monitoring, ten storm water samples were collected directly from the gutter at each of the three sites, simultaneously (Figure 2-12). Samples were collected in graduated cylinders and/or sterile, wide-bore syringes (depending on rate of flow in the gutter) and were transferred to containers appropriate for the analysis to be conducted. All samples were collected during the first flush of the storm event on the ascending limb of the hydrograph.[6]

Figure 2-12. Curbline Wet Weather Sampling – McClintock

All samples were collected in laboratory-certified, constituent-free sample bottles. Field staff wore powder-free nitrile gloves (or similar) at all times during sample collection. All sampling personnel were trained according to field sampling standard operating procedures. Each sample was uniquely identified with sample labels in indelible ink. All sample containers were identified with the project title, appropriate identification number, the date and time of sample collection and preservation method. Samples were kept on ice, under chain of custody (Appendix C) and delivered to the appropriate laboratory (CRG Marine Laboratories) within the required holding time.

A field data log of empirical observations of the site and water quality characteristics was completed at each site during each storm event (Appendix E). Meteorological conditions (i.e., odor, color, and general turbidity of the runoff) at the time of sampling, changes in vegetation, number of parked cars, and other observations were noted on field data logs. Photographs were also taken during each site visit, as warranted.

[6] Sampling was concluded within an hour of the onset of flow in the gutters.

Ten discrete samples from each site (i.e., a total of 30 samples per storm event) were analyzed for total suspended solids (TSS); hardness; and total and dissolved copper, lead, and zinc. Separate samples (i.e., three samples per storm event) were collected, composited, and analyzed for synthetic pyrethroids at each site. The sampling and analysis regime is summarized in Table 2-6.

Table 2-6. Sampling Regime for Each of Three Storm Events in the Chollas Creek Subwatershed

Site / Machine	No. Samples Collected	Constituents Analyzed Individually	Total No. Individual Analyses (all sites)	Constituents Analyzed as a Composite	Total No. Composite Analyses (all sites)
Meade Avenue (west) – Mechanical	10	TSS; hardness; and total and dissolved copper, lead, and zinc	30	Synthetic pyrethroids	3
Meade Avenue (east) – Vacuum	10	TSS; hardness; and total and dissolved copper, lead, and zinc		Synthetic pyrethroids	
McClintock Street Mechanical, unswept	10	TSS; hardness; and total and dissolved copper, lead, and zinc		Synthetic pyrethroids	

2.5.3 Water Quality Analysis Protocols

Samples were analyzed by CRG Marine Laboratories, a laboratory certified by the California Environmental Laboratory Accreditation Program (ELAP). Discrete and composite storm water samples were analyzed using the methods, method detection limits, and reporting limits provided in Table 2-7.

Table 2-7. List of Analytes and Methods Used for Wet Weather Samples

Analyte	Method	Units	MDL	RL (lab)	WQO	Source	Type of Sample
General Chemistry							
TSS	SM 2540-D	mg/L	0.5	0.5	–	–	Discrete
Total hardness as $CaCO_3$	SM 2340-B	mg/L	1	5	–	–	Discrete
Metals							
Total copper (Cu)	EPA 200.8	µg/L	0.4	0.8	–	–	Discrete
Total lead (Pb)	EPA 200.8	µg/L	0.1	0.5	–	–	Discrete
Total zinc (Zn)	EPA 200.8	µg/L	0.1	0.5	–	–	Discrete
Dissolved copper (Cu)	EPA 200.8(m)	µg/L	0.4	0.8	Hardness dependent	California Toxics Rule	Discrete
Dissolved lead (Pb)	EPA 200.8(m)	µg/L	0.1	0.5	Hardness dependent	California Toxics Rule	Discrete
Dissolved zinc (Zn)	EPA 200.8(m)	µg/L	0.1	0.5	Hardness dependent	California Toxics Rule	Discrete
Synthetic Pyrethroid Pesticides							
Allethrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Bifenthrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Cyfluthrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Cypermethrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Danitol (Fenpropathrin)	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Deltamethrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
L-Cyhalothrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Permethrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite
Prallethrin	NCI-GCMS	ng/L	0.5 *	2.0 *	–	–	Composite

*Reasonably expected MDL and RL with cited performance-based GCMS Method.

3.0 MACHINE EFFECTIVENESS RESULTS

3.1 Debris Weights

A robust dataset of swept debris weights and associated number of broom miles was compiled during the two-year pilot study. Broom miles were used to normalize the debris weight swept in a given week and allowed meaningful comparison of debris weight data from week to week and route to route. Normalizing the data also made it unnecessary to discard data for the following reasons:

- Route incompleteness. Incomplete routes were flagged according to the 80% of route swept completeness criterion.
- Debris from two different types of machines or two different sweeping frequencies comingled in the same study bin.
- Rain. The pilot study was designed to evaluate dry weather conditions. Rainfall during the week of sweeping and sampling caused the debris to be muddier (heavier) and therefore skewed the debris weight data.
- When the mechanical sweeper had to be used in place of the vacuum due to the type of debris encountered along the route. This evaluation was based upon the best professional judgment of the sweeper operators, Storm Water Department project managers, and Weston staff. Large branches, sticks, mud, etc. could be swept by the mechanical machine after multiple trips along the route, thus skewing both the weight and broom mile data.

According to the original pilot study design, each type of street sweeper was scheduled to operate along a given route for three to four consecutive weeks before switching to the next machine in the rotation schedule. If debris chemistry monitoring was ongoing for a specific machine, sweeping operations along the route were discontinued if the necessary study machine was out-of-service.[7] The availability of debris weight data was contingent on normal sweeping operations and practices at the City. Sweeping was not conducted during public holidays or rainy days due to safety protocols and machine operations.

3.1.1 Route 3J and Route 1C

Debris weight data were collected for Chollas Creek Route 3J between May 2008 and June 2009. This mixed commercial/residential route is approximately 14 miles long and has a relatively flat, rough asphalt surface. The weekly debris weight data for the mechanical, regenerative-air, and vacuum sweepers are presented on Figure 3-1. All of the debris weight data are presented in tabular form in Appendix F.

Based on the Route 3J data, the vacuum sweeper proved more effective in removing debris than either the regenerative-air or mechanical machines, with mean removal rates of 82.1, 54.0, and 37.1 pounds of debris removed per broom mile, respectively. Although the amount of debris removed per broom mile was variable from week to week for each machine, the results from

[7] In the event that a machine was out-of-service for more than two weeks, standard policy was to sweep the route with the mechanical sweeper in order to maintain the aggressive sweeping frequency and to ensure good public relations.

Route 3J suggest that the vacuum machine removed, on average, more than twice as much debris as the mechanical machine (a 121% increase) and 54% more debris than the regenerative-air machine. Thus, the results suggest that the vacuums sweeper is the most effective of the three machines assessed in removing debris from the street surface on this route.

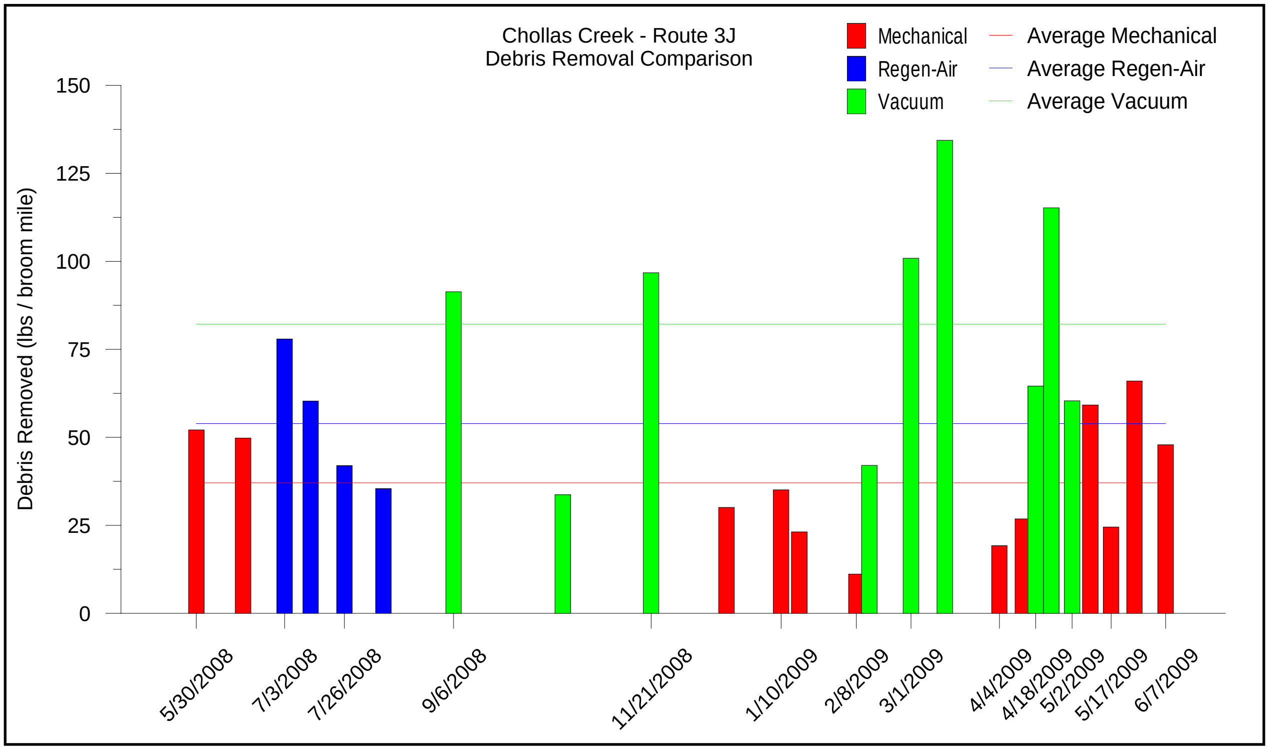

Figure 3-1. Debris Removal (pounds per broom mile) by Machine Type for Chollas Creek Route 3J

Based on the initial results for Route 3J, preliminary debris removal data were also collected for La Jolla Shores Route 1C for the mechanical and vacuum sweepers between March 2009 and February 2010. Route 1C covers approximately 45 broom miles, includes long and hilly major connectors, and consists of mostly commercial land use. The debris weight data for the mechanical and vacuum sweepers are presented on Figure 3-2. All of the debris weight data are presented in tabular form in Appendix F. In contrast to route 3J where the vacuum machine removed more than two times the amount of debris as the mechanical machine, the vacuum sweeper in La Jolla Route 1C removed an average of 68.6 pounds of debris per broom mile compared to 57.3 pounds per broom mile removed by the mechanical sweeper; an increase of approximately 20%.

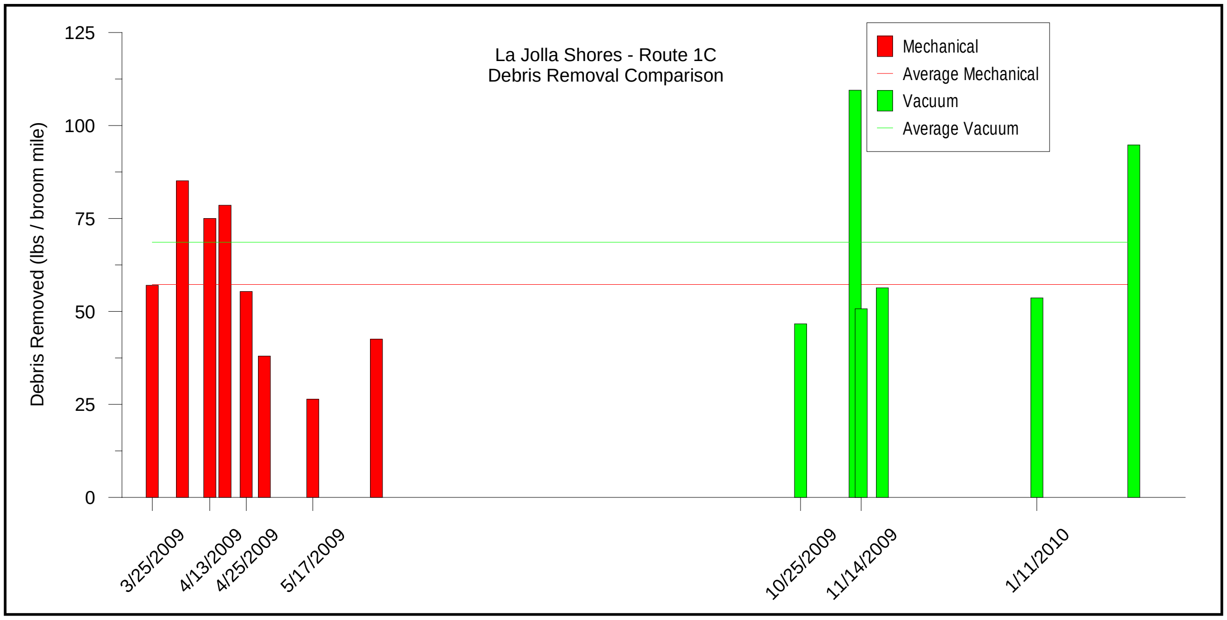

Figure 3-2. Debris Removal (pounds per broom mile) by Machine Type for La Jolla Shores Route 1C

The debris removal results indicate that the vacuum sweeper is more efficient than the mechanical sweeper along Route 3J and may be marginally more efficient along Route 1C. Site-specific differences (e.g., terrain, topography, etc.) may have affected machine performance. The results for both routes are summarized on Figure 3-3.

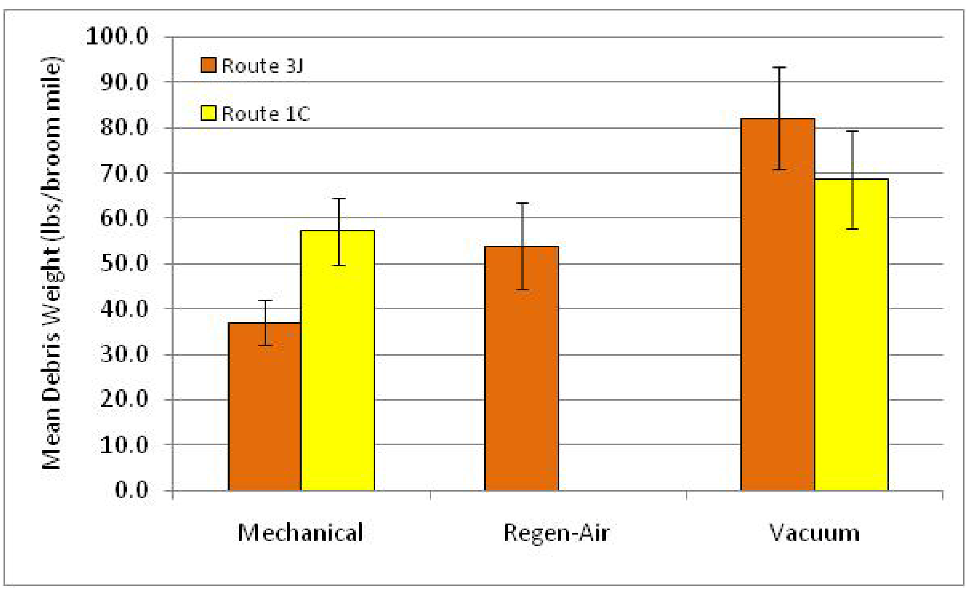

Figure 3-3. Machine Effectiveness by Mean Debris Weight ± Standard Error for Chollas Creek Route 3J and La Jolla Shores Route 1C

3.1.2 Other Routes

Debris weight data were also collected for the mixed commercial/residential Route 103 in the La Jolla Shores Subwatershed, which includes residential and commercial arterials (beach roads), Torrey Pines Road, and La Jolla Shores Drive (Figure 3-4). The mean debris removed over the entire program by machine type for this route is summarized on Figure 3-5. Debris weight data for the Tecolote Creek residential routes 617 and 618 are presented on Figure 3-6. All three sweepers were used in La Jolla Shores, while the mechanical and regenerative-air sweepers were used in Tecolote Creek. All of the debris weight data are presented in tabular form in Appendix F.

The mean debris weight for the mechanical sweeper on La Jolla Shores Route 103 was 133.4 lbs/broom mile, 135.2 lbs/broom mile for the regenerative-air sweeper, and 157.4 lbs/broom mile for the vacuum sweeper (Figure 3-5). The amount of debris removed by each machine varied substantially from week to week (Figure 3-4), which is similar to results seen in other subwatersheds assessed. However, based on the mean debris weights, the results suggest that the regenerative air and mechanical sweepers performed similarly in removing debris from Route 103. The vacuum sweeper performed slightly better along Route 103 than the other two machines (i.e. removed 18% more debris than the mechanical sweeper), but the result is not statistically significant due to an overlap in standard error. These results support the findings of the debris removal assessment for La Jolla Shores Route 1C (Figure 3-3), which suggested high variability in debris removal rates from week to week and site-specific performance differences between the different machines assessed.

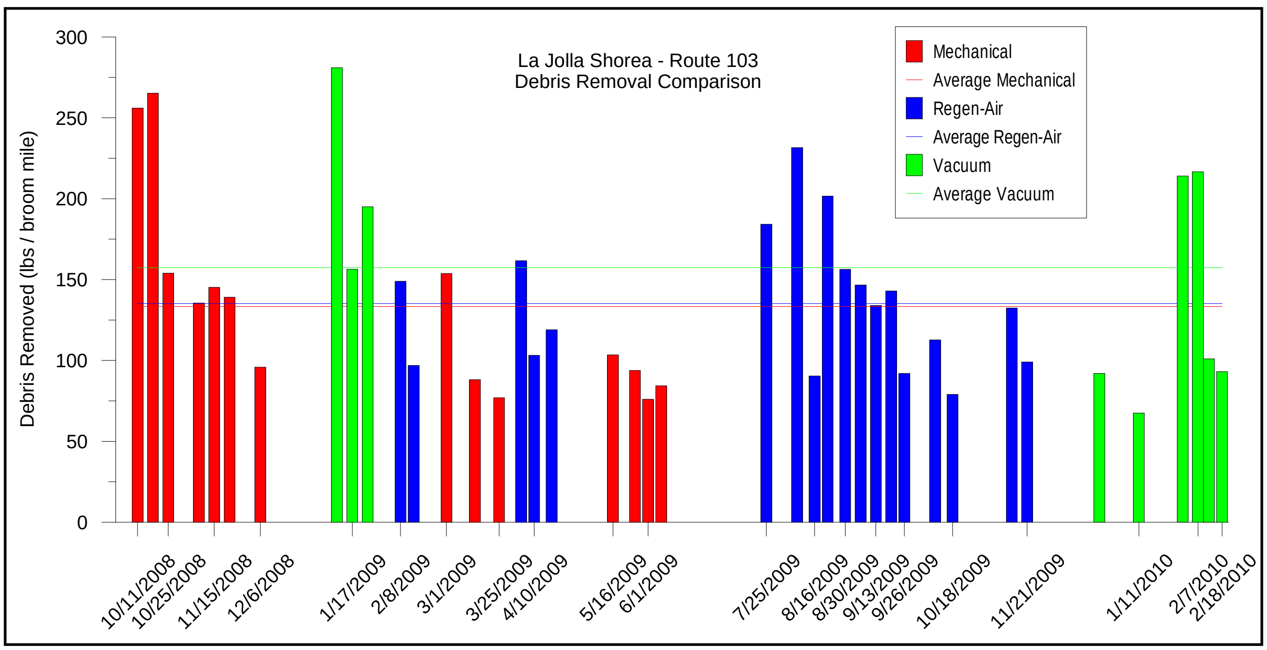

Figure 3-4. Removal (pounds per broom mile) by Machine Type for La Jolla Shores Route 103

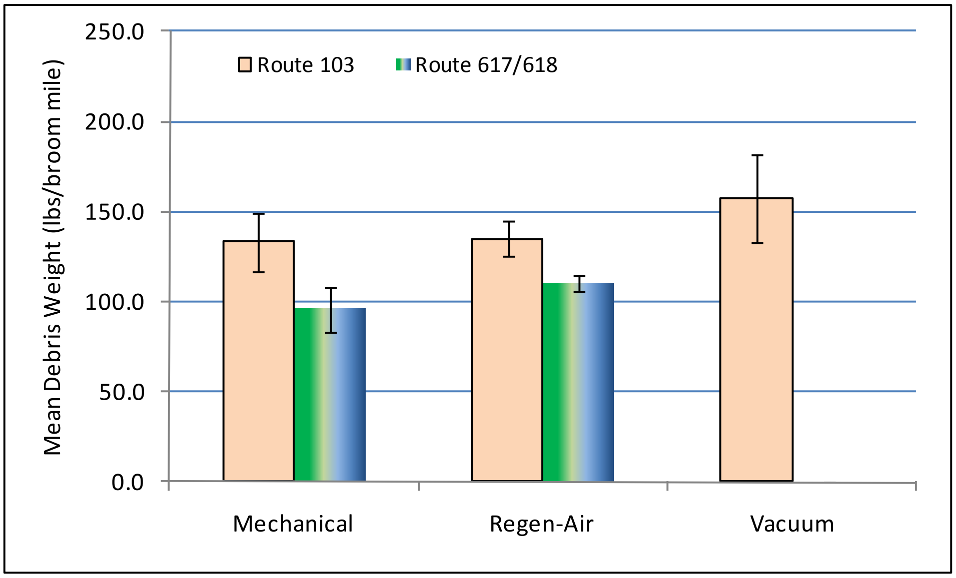

Figure 3-5. Machine Effectiveness by Mean Debris Weight ± Standard Error for La Jolla Shores Route 103 and Tecolote Creek Routes 617/618

In the Tecolote Creek Subwatershed, debris removal results from combined route 617/618 were available for the mechanical and regenerative-air sweepers. The mean debris weight for the mechanical sweeper for routes 617/618 was 95.9 lbs/broom mile, which was very similar to that of the regenerative-air sweeper, which removed an average of 110.4 lbs/broom mile (Figure 3-5). The variability of the data (Figure 3-6) and the small difference between the means when the standard error is taken into account suggest that mechanical and regenerative air machines performed similarly in removing debris from Tecolote Creek Routes 617 and 618.

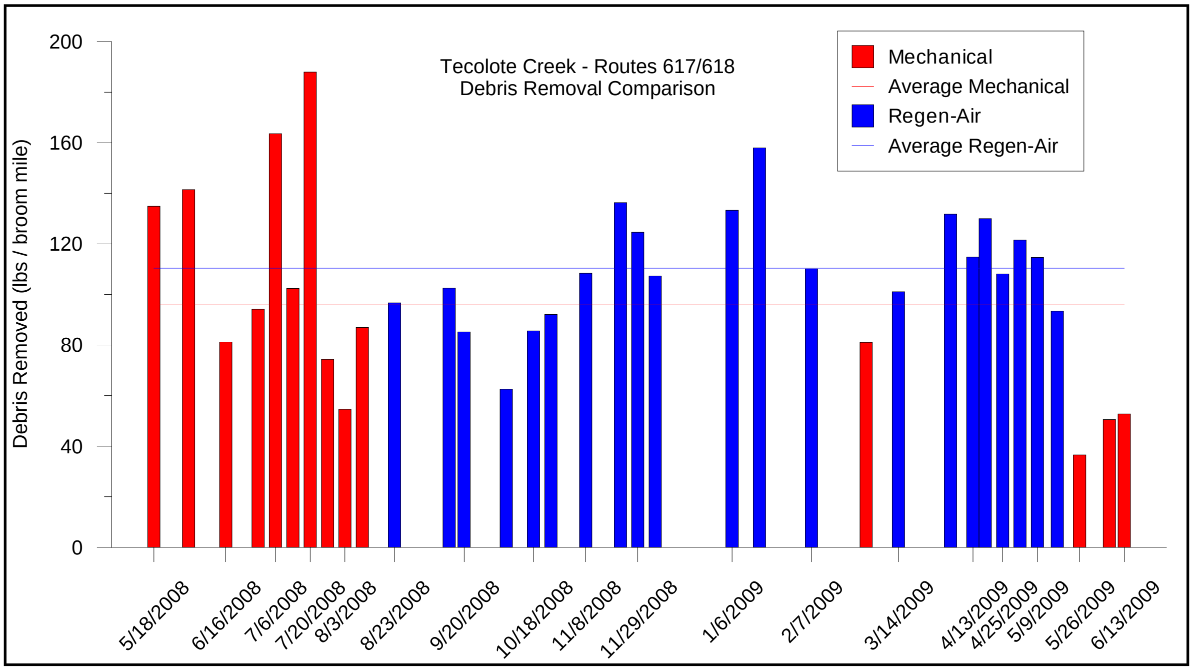

Figure 3-6. Machine Effectiveness by Mean Debris Weight ± Standard Error for Tecolote Creek Routes 617 and 618

3.2 Grain Size

Some studies have suggested that newer sweeping technologies, such as the regenerative-air and vacuum-assisted sweepers, are able to remove finer particulate matter compared with standard mechanical sweepers (Pitt et al., 2004). To test this assertion, samples of the debris removed as part of the machine effectiveness assessment discussed above were analyzed for grain size to evaluate whether the newer technologies were more effective in removing fine-grained particles.

The debris grain-size results are shown in Figure 3-7. The mean grain size and debris composition are summarized by sweeper type and routes in Table 3-1. In general, the debris mostly consisted of large-grained material in the sand (0.074 to 1.99 mm) and gravel size classes (2.0 to 4.0 mm). Swept debris consisted of a smaller portion of silt (0.004 to 0.073 mm) and clay (< 0.004 mm) size classes. The mean median grain size diameter of swept debris for all routes and machine types was 0.80 mm, which is predominantly sand.

Although sand was the dominant size class for all sweepers in all subwatersheds assessed, the median size of the particles varied by sweeper type and route. Debris from Chollas Creek Route 3J collected by the mechanical sweeper had an average median grain size of 0.849 mm, which was 86% larger than the average grain size collected by the vacuum sweeper in that subwatershed (0.457 mm) (Table 3-1). In contrast, in La Jolla Shores Route 1C, the average median grain size was similar in debris collected by the mechanical sweeper (1.007 mm) and the vacuum sweeper (0.911 mm). The grain size data potentially indicates how route-specific differences may impact sweeper performance. The vacuum sweeper was able to remove smaller sand particulates than the regenerative-air or mechanical sweepers along relatively flat route Route 3J, whereas the same machine had not improved performance relative to the other sweepers in La Jolla Shores. A discussion of the impact of terrain on sweeper performance is further elaborated in Section 6.1.

Table 3-1. Mean Grain Size and Distribution by Sweeper Type and Route

Watershed	Analytical Category	Number	Mean of the Median Grain Size (mm)	Mean % Gravel	Mean % Sand	Mean % Silt/Clay
Chollas Creek Subwatershed	**ROUTE 3J**	**12**	**0.629**	**14.4**	**78.5**	**7.2**
	3J - Mechanical	5	0.849	20.9	73.1	6.0
	3J - Regenerative-Air	2	0.507	13.7	78.4	8.0
	3J - Vacuum	5	0.457	8.1	83.9	8.0
La Jolla Shores Subwatershed	**ROUTE 1C**	**6**	**0.959**	**17.4**	**78.6**	**4.0**
	1C - Mechanical	3	1.007	21.6	75.4	3.0
	1C - Vacuum	3	0.911	13.2	81.8	5.0
	Route 103	**7**	**0.747**	**15.9**	**77.5**	**6.6**
	103 - Mechanical	4	0.750	17.6	75.4	7.0
	103 - Regenerative-Air	3	0.743	13.7	80.3	6.0

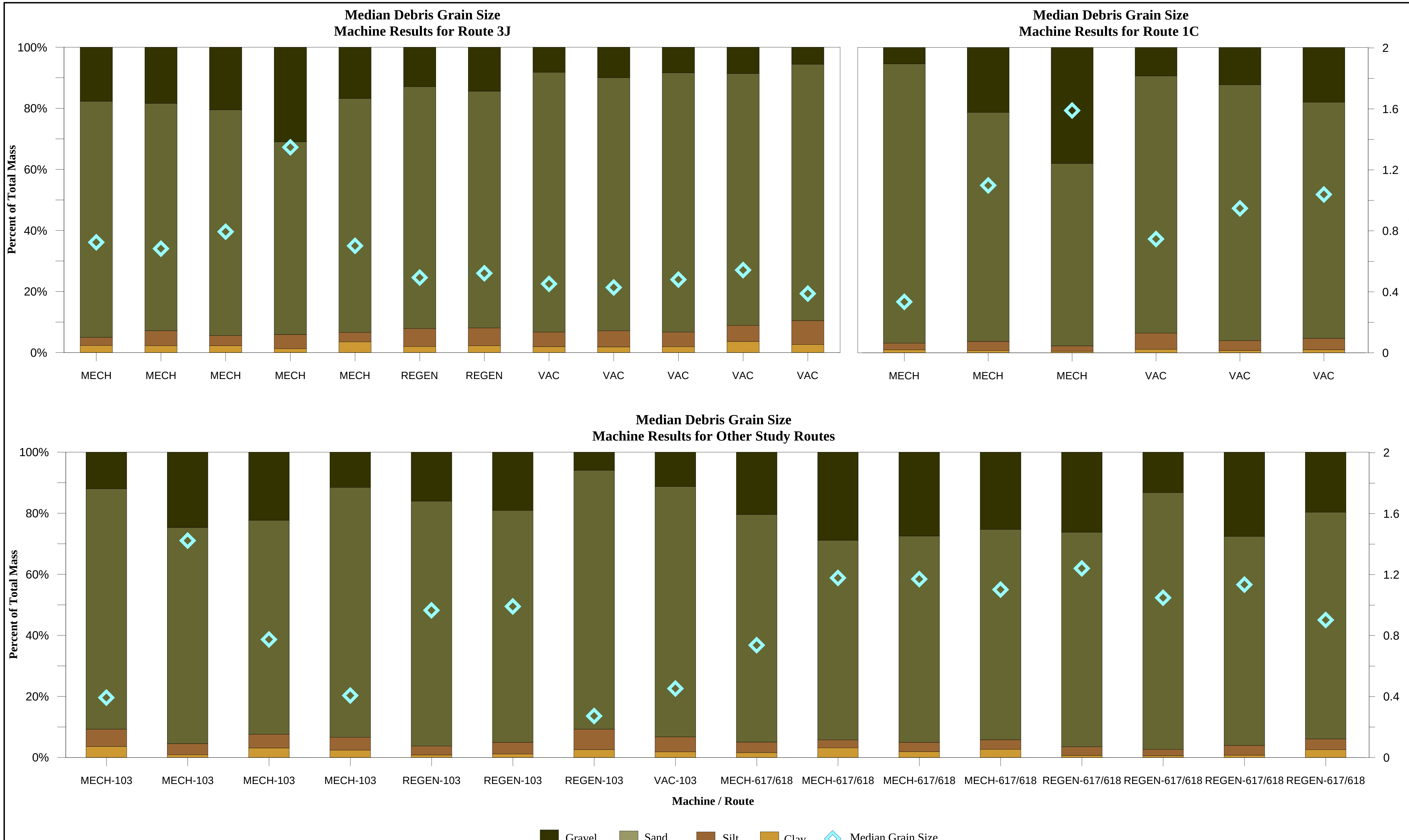

Figure 3-7. Grain-Size Distributions of Debris Collected by Three Types of Sweepers along all Targeted Aggressive Street Sweeping Study Routes

3.3 Swept Debris Chemistry Analysis

3.3.1 Route 3J and Route 1C

Street sweeper debris was analyzed for a suite of chemical parameters to determine the effectiveness of constituent removal among the machine types compared. Chemical analysis was performed on debris collected from the Chollas Creek Route 3J between May 2008 and May 2009 and from the La Jolla Shores Route 1C between October and November, 2009. Chemistry results were converted into normalized metals loads (grams per broom mile) for total copper, lead, and zinc by multiplying metal concentration by pounds of debris removed (Figure 3-1 and Figure 3-2). The results are shown in Table 3-2. Loads were assessed for all three sweeper types for Chollas Creek Route 3J, but only for the mechanical and vacuum sweepers (the only two sweeper types used) for La Jolla Shores Route 1C. The machine effectiveness assessment for copper, lead, and zinc loads are summarized on Figure 3-8 for Route 3J and on Figure 3-9 for Route 1C. The complete sediment chemistry dataset is presented in Appendix G.

In the Chollas Creek Subwatershed, the results suggest that the vacuum sweeper was more effective than the mechanical and regenerative sweepers in removing metals from the street surface. Based on the mean load for each machine type, the vacuum sweeper removed 65% more copper than the mechanical machine (1.67 g/broom mile compared to 1.01 g/broom mile), nearly three times as much lead (1.75 g/broom mile compared to 0.62 g/broom mile), and 45% more zinc (6.58 g/broom mile compared to 4.54 g/broom mile), as shown in Table 3-2 and Figure 3-8. Chemistry data for the regenerative air sweeper were available for only two weeks of sweeping. The mean concentrations of metals from this limited data set suggest that the regenerative-air sweeper was less effective in removing metals from the street surface than either the mechanical or vacuum sweepers.

In the La Jolla Shores Subwatershed, the load results suggest that the metals loads were greater for the vacuum sweeper than the mechanical sweeper (Table 3-2). The vacuum sweeper mean total copper load was nearly five times greater for the vacuum sweeper (2.13 g/broom mile) compared to the mechanical sweeper (0.45 g/broom mile) and the mean total zinc load was nearly three times greater for the vacuum sweeper compared to the mechanical sweeper (4.45 g/broom mile and 1.64 g/broom mile, respectively) (Table 3-2 and Figure 3-9). It is important to note that the loads discussed in Table 3-2 are a product of the debris removed and the metals concentration. The results of the debris assessment for La Jolla Shores Route 1C (Figure 3-3) suggested only a marginal difference between the amount of debris removed by the vacuum sweeper compared to the mechanical sweeper. Thus, the large difference for total copper and total zinc seen in the metals loads (Table 3-2) was driven primarily by high copper and zinc concentrations in the swept debris. An interpretation of these results with respect to machine effectiveness in the La Jolla Shores Subwatershed is presented in the Discussion (Section 7.0).

In addition to metals, measurable quantities of synthetic pyrethroids (i.e., Bifenthrin and Cypermethrin) were found in debris swept by all machines, along all study routes (Appendix G). The organophosphorus pesticide, Chlorpyrifos, was detected once in debris swept by the mechanical sweeper along Route 3J (May 2009). There were no clear patterns in the pesticide loads relative to sweeper type.

Table 3-2. Machine Effectiveness by Metals Loading for Routes 3J and 1C

Route	Machine	Route Sweeping Frequency	Broom Miles Swept/ Week	Debris Swept/ Week (lbs)	Copper (g/broom mile)	Lead (g/broom mile)	Zinc (g/broom mile)
3J	Mechanical	Twice per week	66	3,438	1.73	0.92	6.27
3J	Mechanical	Twice per week	63	3,282	0.63	0.51	3.60
3J	Mechanical	Twice per week	81	4,035	0.58	0.96	4.73
3J	Mechanical	Once per week	50	2,960	1.49	0.38	3.01
3J	Mechanical	Once per week	40	980	0.24	0.31	5.84
3J	Mechanical	Once per week	50	3,300	1.40	0.63	3.81
MEAN	Mechanical	–	58	2,999	1.01	0.62	4.54
3J	Regenerative-air	Twice per week	162	3,084	0.45	0.47	1.74
3J	Regenerative-air	Twice per week	184	2,957	0.48	0.61	1.49
MEAN	Regenerative-air	–	173	3,021	0.47	0.54	1.62
3J	Vacuum	Twice per week	59	3,160	1.27	1.40	5.99
3J	Vacuum	Twice per week	67	6,760	1.79	1.24	5.36
3J	Vacuum	Twice per week	50	6,720	1.33	2.31	9.21
3J	Vacuum	Once per week	53	3,420	0.75	0.73	2.96
3J	Vacuum	Once per week	50	5,760	3.52	1.96	10.48
3J	Vacuum	Once per week	50	3,020	1.38	2.85	5.48
MEAN	Vacuum	–	55	4,807	1.67	1.75	6.58
1C	Mechanical	Once per week	70	5,500	0.33	0.22	1.55
1C	Mechanical	Once per week	69	3,820	0.75	0.27	2.04
1C	Mechanical	Once per week	83	2,660	0.26	0.11	1.35
MEAN	Mechanical	–	74	3,993	0.45	0.20	1.64
1C	Vacuum	Once per week	78	3,640	0.81	0.30	3.51
1C	Vacuum	Once per week	41	2,080	1.62	0.22	3.43
1C	Vacuum	Once per week	82	4,620	3.95	0.33	6.41
MEAN	Vacuum	–	67	3,447	2.13	0.28	4.45

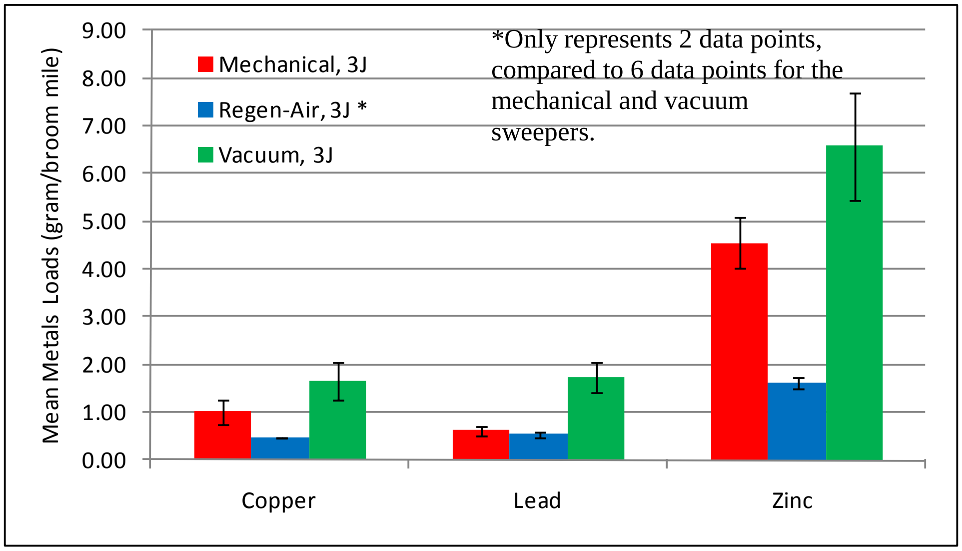

Figure 3-8. Machine Effectiveness by Mean Metals Load ± Standard Error for Chollas Creek Route 3J

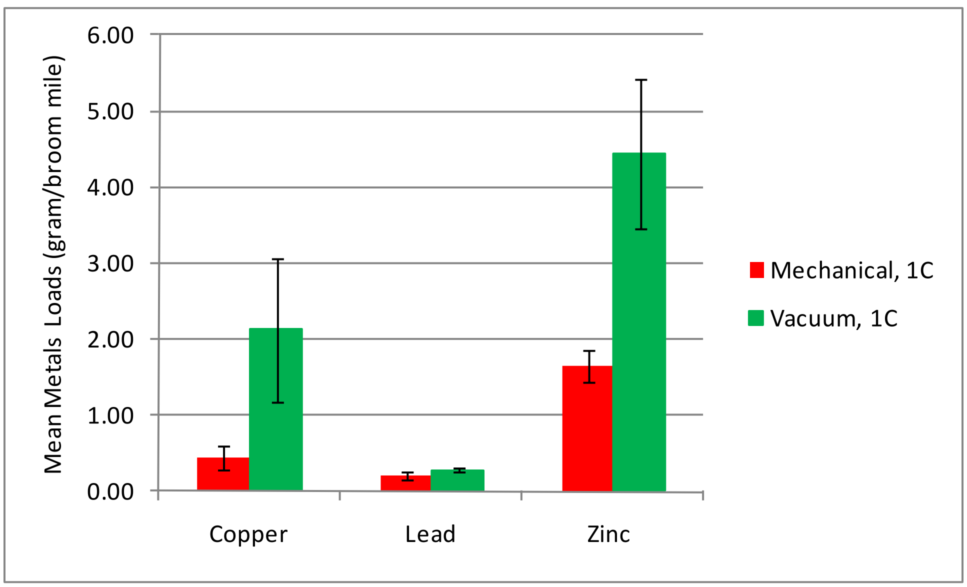

Figure 3-9. Machine Effectiveness by Mean Metals Load ± Standard Error for La Jolla Shores Route 1C

3.3.2 Other Routes

Chemistry data for swept debris were also collected for La Jolla Shores Route 103 and the two Tecolote Creek residential routes 617 and 618. The chemistry results were converted into normalized metals loads for copper, lead, and zinc as summarized in Table 3-3 and presented on Figure 3-10. In addition to metals, measurable quantities of synthetic pyrethroids (i.e., Bifenthrin and Cypermethrin) were found in debris swept by all machines along these routes. The organophosphorus pesticide, Malathion, was detected twice in debris swept by the mechanical sweeper along Route 103 (May 2009). All of the chemistry data are presented in Appendix G.

Table 3-3. Machine Effectiveness by Metals Loading for Routes 103, 617, and 618

Route	Machine	Broom Miles Swept per Week	Debris Swept per Week (lbs)	Copper (g/broom mile)	Lead (g/broom mile)	Zinc (g/broom mile)
103	Mechanical	23	2,380	2.86	0.54	5.57
103	Mechanical	29	2,720	1.99	0.90	5.42
103	Mechanical	20	1,520	0.87	0.41	3.00
MEAN	Mechanical	24	2,207	1.91	0.62	4.66
103	Regenerative-air	19	1,960	1.10	0.67	3.52
103	Regenerative-air	20	2,380	1.30	0.59	4.25
103	Regenerative-air	37	3,120	1.02	0.52	2.56
MEAN	Regenerative-air	25	2,487	1.14	0.59	3.44
617/618	Mechanical	57	2,080	0.39	0.26	4.03
617/618	Mechanical	80	4,040	1.07	0.55	8.99
617/618	Mechanical	49	3,060	1.47	0.31	7.14
MEAN	Mechanical	62	3,060	0.98	0.37	6.72
617/618	Regenerative-air	40	5,200	4	1	10
617/618	Regenerative-air	37	4,000	2	1	10
617/618	Regenerative-air	41	4,700	2	1	10
MEAN	Regenerative-air	39	4,633	2.45	1.05	10.14

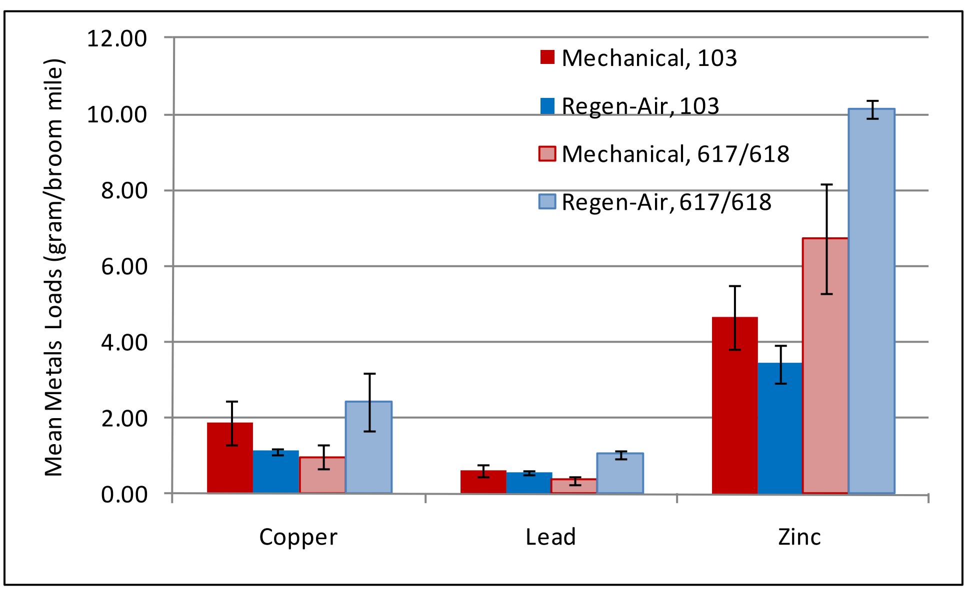

Figure 3-10. Effectiveness by Mean Metals Load ± Standard Error for Route La Jolla Shores Route 103 and Tecolote Creek Routes 617/618

3.3.3 Pesticides

In recent years, there has been an observed shift in pesticide use from banned organophosphorus pesticides products (e.g., Diazinon) to synthetic pyrethroids. Over the course of this two-year pilot study, there were only three detections of organophosphorus pesticides (Chlorpyrifos and Malathion) in swept debris. Diazinon was not detected in any of the swept debris in any of the three subwatersheds included in this study.

In contrast, measurable quantities of synthetic pyrethroids (Bifenthrin and Cypermethrin) were found in debris swept from all study routes. Each machine's effectiveness at removing these synthetic pesticides from streets based on the average concentration in swept debris is summarized in Table 3-4. The pyrethroid data were extremely variable and there were no apparent patterns related to street sweeping. An removal efficiency could not be determined.

Table 3-4. Summary of Synthetic Pyrethroid Pesticide Concentrations by Sweeper Type

Sweeper Type	Sample Size	Bifenthrin Concentration (ng/ g swept debris)	Cypermethrin Concentration (ng/g swept debris)
Mechanical	15.00	121.34 ± 33.51	23.99 ±5.23
Regenerative-Air	8.00	97.27 ± 25.72	25.10 ± 4.99
Vacuum	9.00	47.34 ± 13.11	14.63 ± 5.10
Pilot Study	**32.00**	**94.51 ± 33.66**	**21.64 ± 5.88**

4.0 SWEEPING FREQUENCY ASSESSMENT RESULTS

4.1 Debris Weight

The debris weight data collected for the Chollas Creek Route 3J were also used to assess the effectiveness of aggressive street sweeping frequencies. The debris weights from mechanical and vacuum sweepers that swept Route 3J either once or twice a week were analyzed for the assessment. The weekly normalized debris weight data are presented on Figure 4-1. The complete dataset is presented in tabular form in Appendix G.

The sweeper frequency data varied with sweeper type. The mean weight of debris removed by the vacuum sweeper was similar for both once and twice per week frequencies, with approximately 80 pounds of debris removed per broom mile swept (Figure 4-2). In contrast, the mechanical sweeper removed substantially more debris at a frequency of once per week compared with a frequency of twice per week.

The results suggest that the vacuum sweeper removes the same amount of debris per mile when sweeping either once or twice per week and thus, doubling the sweeping frequency of the vacuum sweeper also doubles the amount of debris removed. In contrast, sweeping efficiency drops with increased frequency with the mechanical sweeper because it removes a smaller volume of debris per mile when employed twice per week. These data suggest that increasing sweeping frequency of the mechanical machine would be less efficient—in terms of debris removed per broom mile swept—than increasing the frequency of the vacuum sweeper. However, given the standard error for all data, the apparent differences in the amounts of debris removed should be viewed in parallel with the constituent (i.e. total metals) removal at the different sweeping frequencies. These results are presented in Subsection 4.2.

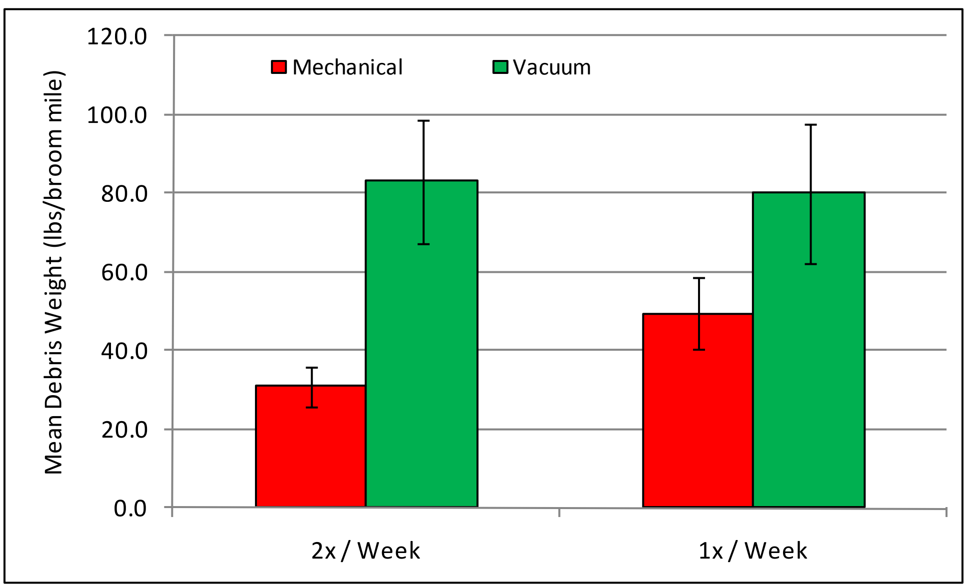

Figure 4-1. Sweeping Frequency Assessment by Mean Debris Weight ± Standard Error for Chollas Creek Route 3J

4.2 Debris Chemistry Analysis for Chollas Creek Route 3J

Chemistry data for swept debris were collected for Chollas Creek Route 3J between May 2008 and May 2009. The chemistry results from debris samples collected from streets swept at the two sweeping frequencies (Table 3-2) were converted into normalized metals loads for copper, lead, and zinc according to sweeping frequency. The results are summarized in Table 4-1 and presented on Figure 4-2. The complete dataset is presented in Appendix G. Unlike the debris removal results discussed in Subsection 4.1, with exception of total lead concentrations, the chemistry results suggest that there are no discernable differences in the effectiveness of constituent removal (i.e., grams of metal removed per broom mile) based on sweeping frequency. For both machines, the mean loads for a given metal were similar for once per week and twice per week sweeping frequencies. These results suggest that both sweeper types remove approximately the same amount of metals per mile when sweeping either once or twice per week. Thus, doubling the sweeping frequency of either machine also doubles the amount of metals removed.

Table 4-1. Sweeping Frequency Effectiveness by Mean Metals Loading

Route	Machine	Route Sweeping Frequency	Broom Miles Swept per Week	Debris Swept per Week (lbs)	Copper (g/broom mile)	Lead (g/broom mile)	Zinc (g/broom mile)
3J	Mechanical	Twice per week	70	3,585	0.98	0.80	4.87
3J	Mechanical	Once per week	47	2,413	1.04	0.44	4.22
3J	Vacuum	Twice per week	59	5,547	1.47	1.65	6.85
3J	Vacuum	Once per week	51	4,067	1.88	1.85	6.31

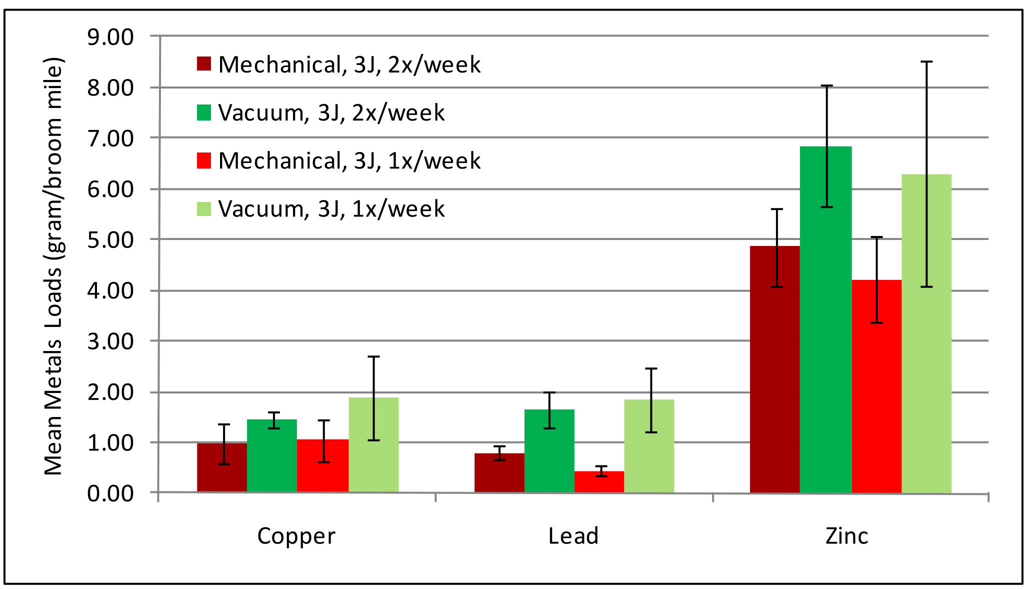

Figure 4-2. Sweeping Frequency Assessment by Mean Metals Load ± Standard Error for Chollas Creek Route 3J

5.0 WATER QUALITY RESULTS

5.1 Storm Events

Three storms were monitored during the 2009–2010 Wet Weather Monitoring Season on December 7, 2009; January 18, 2010; and February 5, 2010. Storm water monitoring was conducted on and adjacent to Meade Avenue in the Chollas Creek Subwatershed. Monitoring details are provided in Subsection 5.2. Representative photographs are shown on Figure 5-1. The first flush and the sampling times for each wet weather monitoring site are presented for each storm event on Figure 5-2. Gutter flow data were not collected at the Meade Avenue location.[8] The rise in flow is based on the first portion of the storm hydrographs for the nearby mass loading station, SD8(1), in the receiving waters of Chollas Creek.

During the December 2009 storm, a total of 0.82 inch of rain fell over approximately 14 hours. Samples were collected during the first 30 minutes of the event, a few minutes after flow was observed in the curb and gutter. Due to flooding at the intersection of McClintock Street and Meade Avenue, grab sampling was moved from the intersection to a point approximately 200 ft upstream (Figure 5-1). The January 2010 storm was the first of a series of rainfall events during the week. During the first six hours of the first storm, 0.15 inches of rain fell at SD8(1). Samples were collected during the first 20 minutes of the event. The storm hydrograph for the February 2010 event spanned several days. Monitoring equipment installed at SD8(1) measured 0.01 inches of rainfall at 20:30. San Diego Weather Underground reported 0.34 inch of rainfall for the region on the following day.

Figure 5-1. Storm Water at Unswept Monitoring Site (January 18, 2010 – left) and Vacuum Monitoring Site (December 7, 2009 – right)

[8] Flow levels in the gutter were less than or equal to two inches in depth and highly variable based on the localized drainage areas. Based on best professional judgment, it was determined that modeling local flows using level data and/or rainfall data was inappropriate.

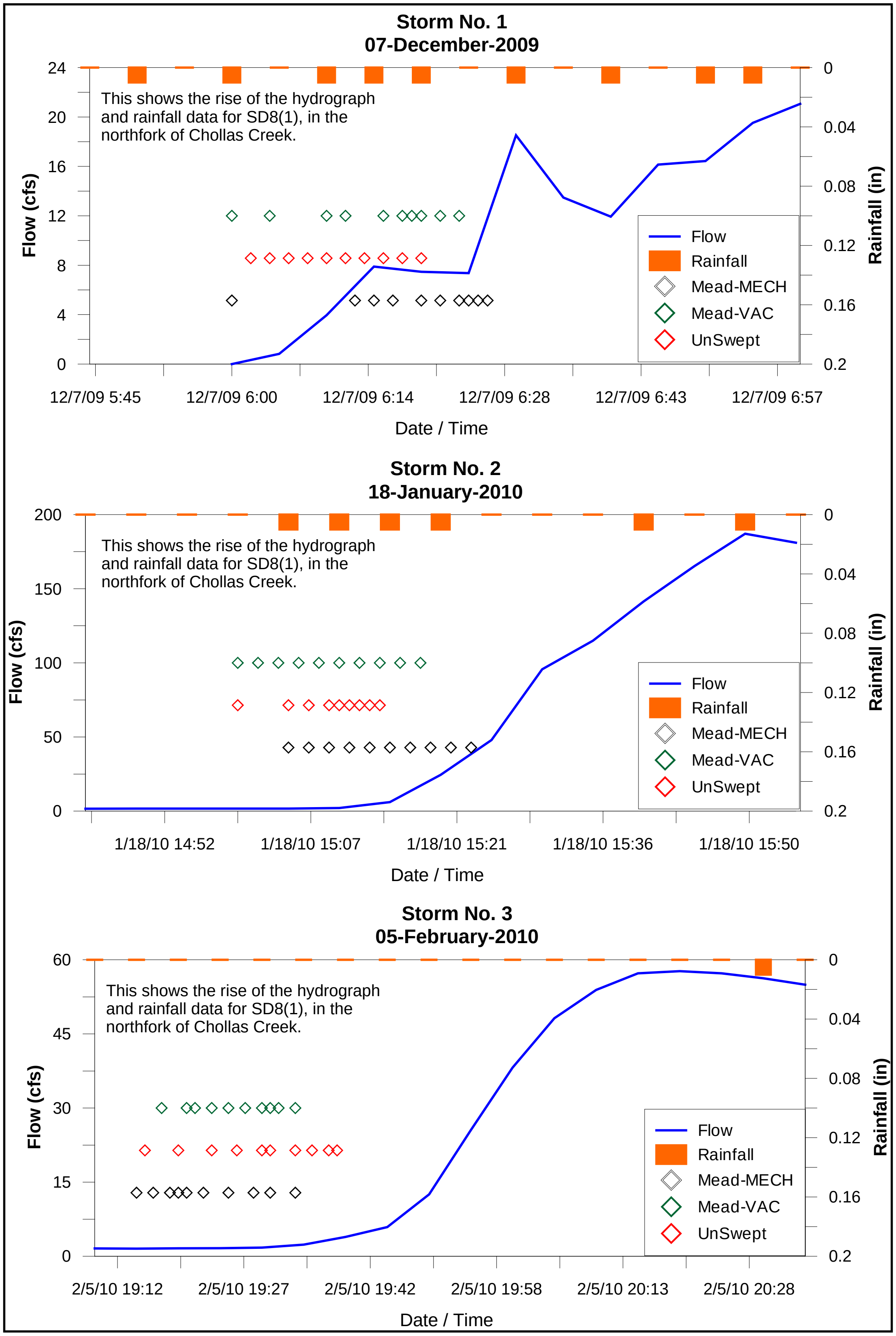

Figure 5-2. First Portion of the Storm Hydrographs in the North Fork of Chollas Creek at Mass Loading Station SD8(1) during the Three Monitored Storm Events in 2009–2010

5.2 Wet Weather Machine Effectiveness Results

The storm water chemistry results for the three monitored storms are summarized by site in Table 5-1. "Vacuum" and "Mechanical" in the table refer to the street segment at that site that had been swept by either the vacuum or mechanical sweeper, once per week and for three continuous weeks prior to a storm event. "Unswept" refers to the site that had been swept once every two months prior to the storm (McClintock Street). The values in the table represent the mean concentration of the ten samples that had been collected at each site at the onset of the storm. The mean of three storms represents the mean of the total metals and TSS concentrations for each of the treatments from the three events combined (n=30 for each treatment). Figure 5-3 provides a graphical representation of the data.

The results suggest that street sweeping is an effective BMP for sediment removal (i.e., TSS) from urban runoff and that the vacuum sweeper is more effective than the mechanical sweeper in sediment removal from storm water. During all three storm events, the mean TSS concentration from the samples collected from the unswept street were significantly greater than the means from samples collected from the street swept with the mechanical sweeper and the street swept with the vacuum sweeper (Figure 5-5). The mean TSS concentrations during the first storm were similar for the streets swept by mechanical and vacuum sweepers. However, concentrations were substantially lower in the vacuum-swept street than the mechanically-swept street in both Storm 2 and Storm 3. Mean TSS concentrations from the unswept street for all three storms (927.0 mg/L) (Figure 5-4) were, on average, four times greater than the mean concentration from the mechanically swept street (243.8 mg/L) and were nearly seven times greater than the mean concentration from the vacuum-swept street (135.8 mg/L) (Table 5-1). In addition, the mean TSS concentration in the vacuum-swept street was half that in the street swept by the mechanical sweeper, suggesting that the vacuum sweeper is more effective in removing sediment from street surfaces than the mechanical machine.

A reduction in TSS is often correlated with a reduction in metals in storm water runoff due to the adherence of metals to particulate matter, especially those in the smaller size classes. In all three storms, concentrations of total copper, total lead, and total zinc were greatest in runoff from the unswept street compared to the street segments swept with mechanical and vacuum sweepers (Table 5-1 and Figure 5-3). Mean concentrations for the three storms reflect this overall pattern as shown on Figure 5-4. Mean total copper (63.1 µg/L), total lead (49.0 µg/L), and total zinc (469.2 µg/L) concentrations in storm water collected from the street swept by the mechanical sweeper were less than half the corresponding mean concentrations from the unswept street (145.0, 121.7, and 1,117.5 µg/L, respectively). In addition, mean metals concentrations in storm water from the street segment swept by the vacuum sweeper were significantly lower than those found in the mechanically swept street. Mean concentrations of total copper, lead, and zinc collected from the vacuum swept street segment had 34% less total copper, 59% less total lead, and 26% less total zinc ($p < 0.05$ for all three events) than the mean concentration from the mechanically swept street segment. The results suggest that street sweeping is effective in removing TSS and metals from storm water runoff and that the vacuum sweeper performs better than the mechanical sweeper in constituent removal during the first flush of a storm event.

Table 5-1. Summary of Mean Total Metals Concentrations in Storm Water Following Three Sweeping Treatments

Storm Event	Type of Sweeping	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)	TSS (mg/L)
12/07/2009	Unswept	143.0	71.8	1,689.4	703.8
	Mechanical	50.9	30.7	443.6	112.8
	Vacuum	51.2	22.3	362.7	130.2
01/18/2010	Unswept	218.4	234.0	1,210.9	1,719.6
	Mechanical	83.1	77.8	610.1	431.6
	Vacuum	34.1	23.5	307.6	145.2
02/05/2010	Unswept	73.7	59.2	452.1	357.6
	Mechanical	55.4	38.5	353.8	187.1
	Vacuum	39.4	15.2	366.1	132.0
Mean of Three Storms	Unswept	145.0	121.7	1,117.5	927.0
	Mechanical	63.1	49.0	469.2	243.8
	Vacuum	41.6	20.3	345.5	135.8

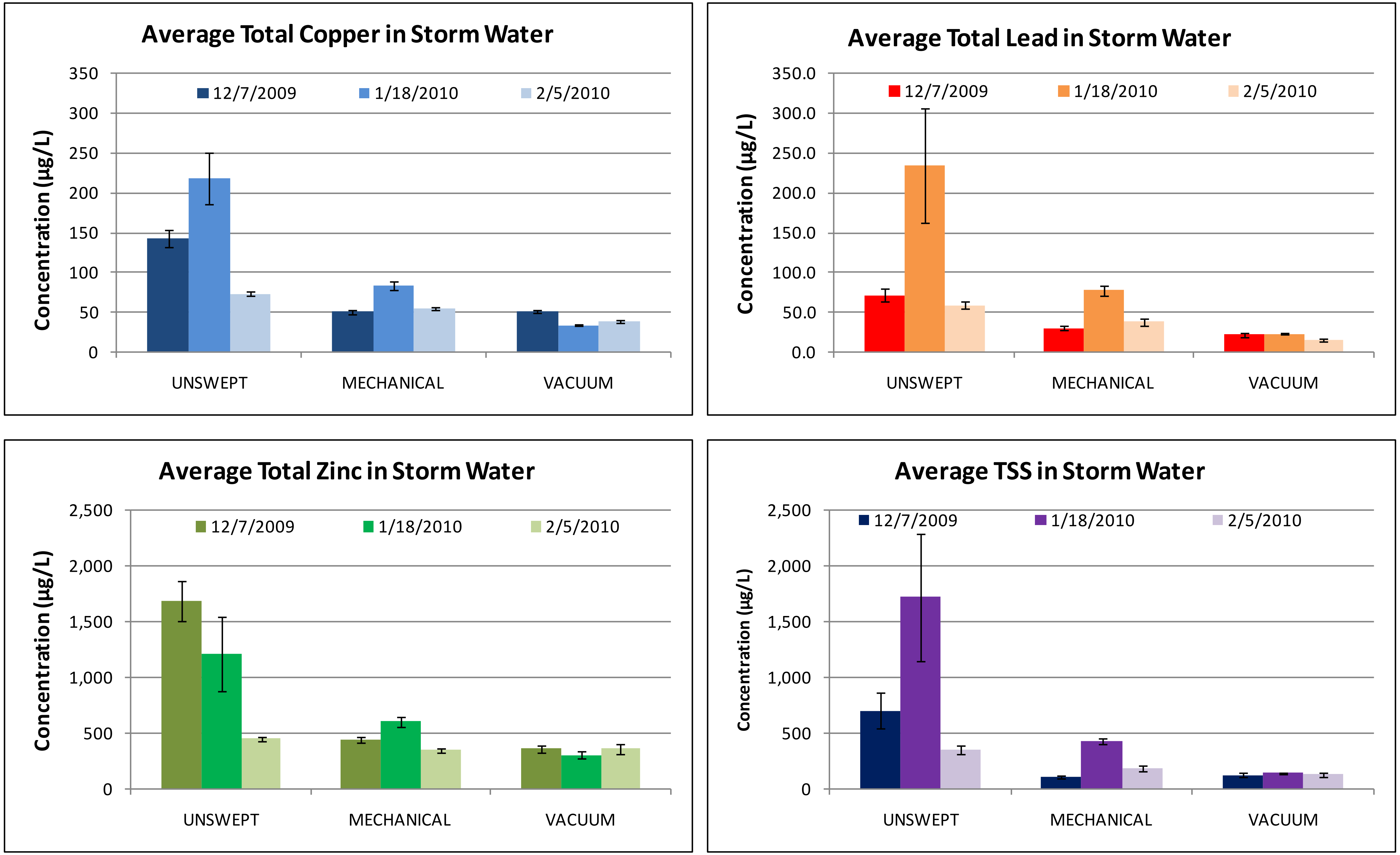

Figure 5-3. Average Total Metals and Total Suspended Solids Concentrations ± Standard Error in Storm Water Runoff from Unswept, Mecahnically-swept and Vacuum-swept Street for Three Monitored Storm Events at a Once per Week Sweeping Frequency (n=10)

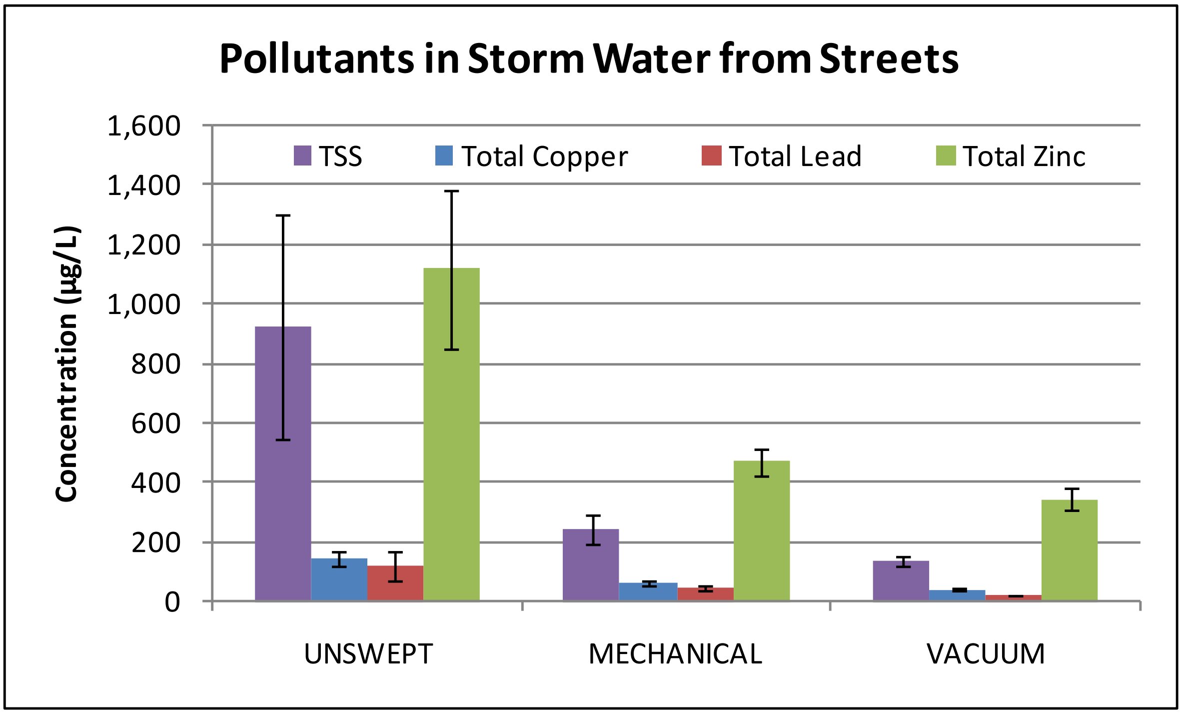

Figure 5-4. Mean Total Metals and Total Suspended Solids Concentrations ± Standard Error in Storm Water Runoff from Unswept, Mecahnically-swept and Vacuum-swept street for Three Monitored Storm Events at a Once per Week Sweeping Frequency (n=30)

5.3 Wet Weather First Flush Pollutographs

In addition to assessing storm water mean concentrations of TSS and total metals from streets with different sweeping types, it is also helpful to compare the relative proportion of dissolved versus total metals over the course of the monitoring event. First flush pollutographs, which depict concentrations of discrete samples collected over the course of the monitoring event (first 30 minutes of the storm), are presented on Figure 5-5, Figure 5-6, and Figure 5-7, for copper, lead, and zinc, respectively. The hydrographs depict the beginning of the storm when monitoring was conducted from the onset of flow in the gutter to the completion of sampling (typically the first 20–30 minutes of the storm), and the metals concentrations show both the dissolved and total fractions of metals in each sample.

The relative proportion of dissolved to total metals concentrations in storm water will vary depending on a variety of chemical and physical factors such as the solubility of the metal and the TSS concentration. In general, the concentration of the dissolved phase of the metal decreases with increasing TSS because the metal preferentially binds with the sediment particles in solution resulting in greater total metals concentrations than dissolved. This pattern can be seen in the pollutographs on Figure 5-5, Figure 5-6, and Figure 5-7. TSS concentrations were greatest in storm water collected from the unswept street (Figure 5-4). The proportions of dissolved metals relative to total metals concentrations were lowest in these samples, compared to those collected from street segments swept with the mechanical and vacuum sweepers. This is most obvious for lead, which is more insoluble than copper or zinc and therefore preferentially binds to sediments more strongly. Thus, the proportions of dissolved lead in the samples from the unswept street, where TSS concentrations were high, were virtually zero.

The extent to which street sweeping can remove dissolved metals is important because the Chollas Creek Dissolved Metals TMDL is based on the concentrations of dissolved copper, lead, and zinc. Therefore, the concentrations of the dissolved phase of these metals during the first flush of the three storm events were compared to the freshwater standards for those metals set forth in the Basin Plan (criterion maximum concentration (CMC)) on Figure 5-5, Figure 5-6, and Figure 5-7, respectively. These criteria were designed for comparison to receiving waters and are not directly applicable to samples collected in the MS4 (or gutter prior to entering the MS4). The use of these criteria is therefore presented for comparison purposes only to assess how street sweeping affects the dissolved metals concentrations relative to the water quality objectives. The freshwater criteria are determined by the hardness at the time of sampling and thus change over the course of the monitoring event. During the three wet weather monitoring events at the three sites, most of the dissolved copper and dissolved zinc concentrations in the pollutographs were greater than the applicable water quality objectives for receiving waters (yellow line in the graph). In contrast, all of the dissolved lead concentrations were below the applicable CMC, including samples collected from the unswept street.

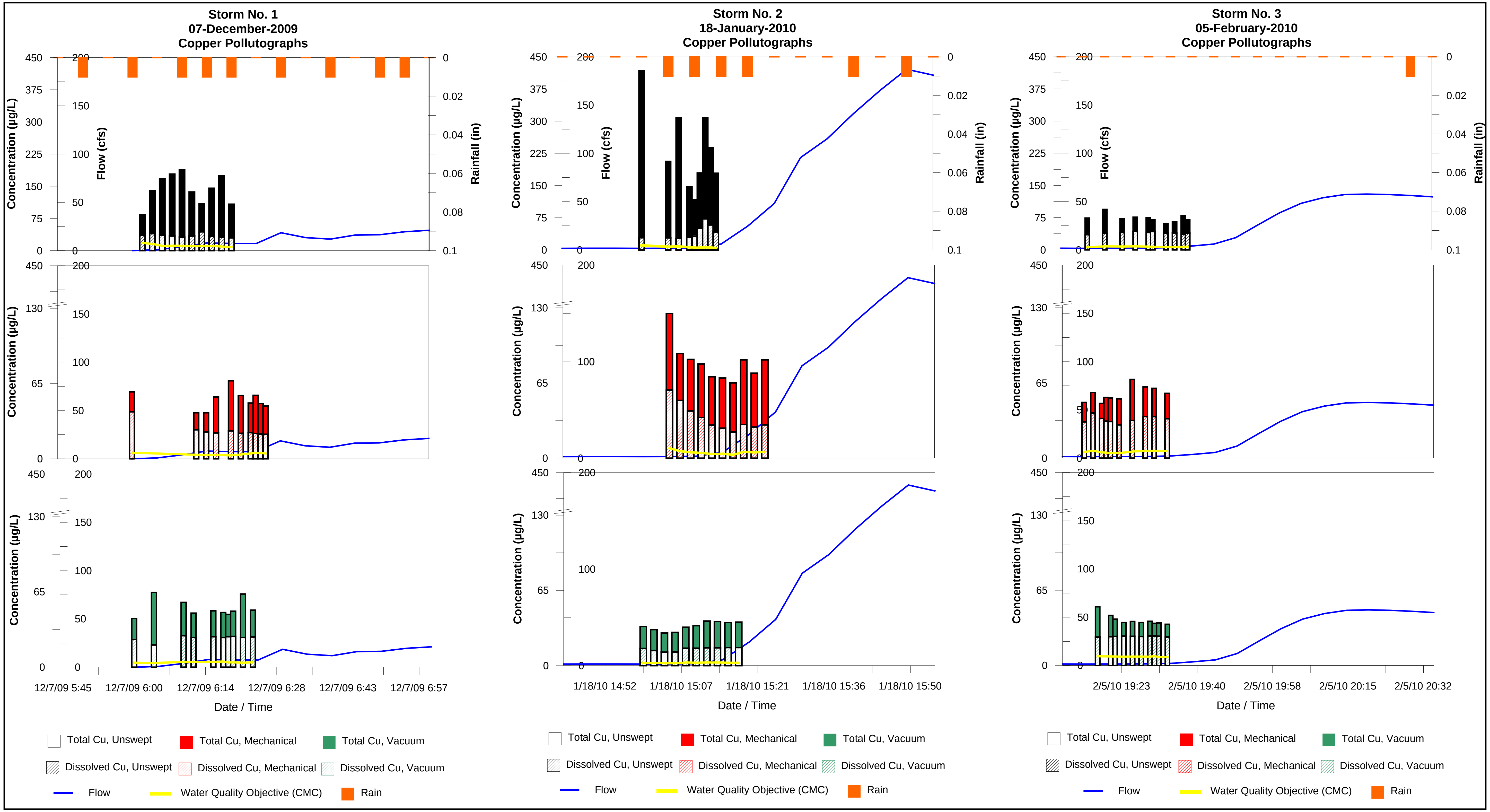

Figure 5-5. Total Copper and Dissolved Copper First Flush Pollutographs for the Each Monitored Storm Event

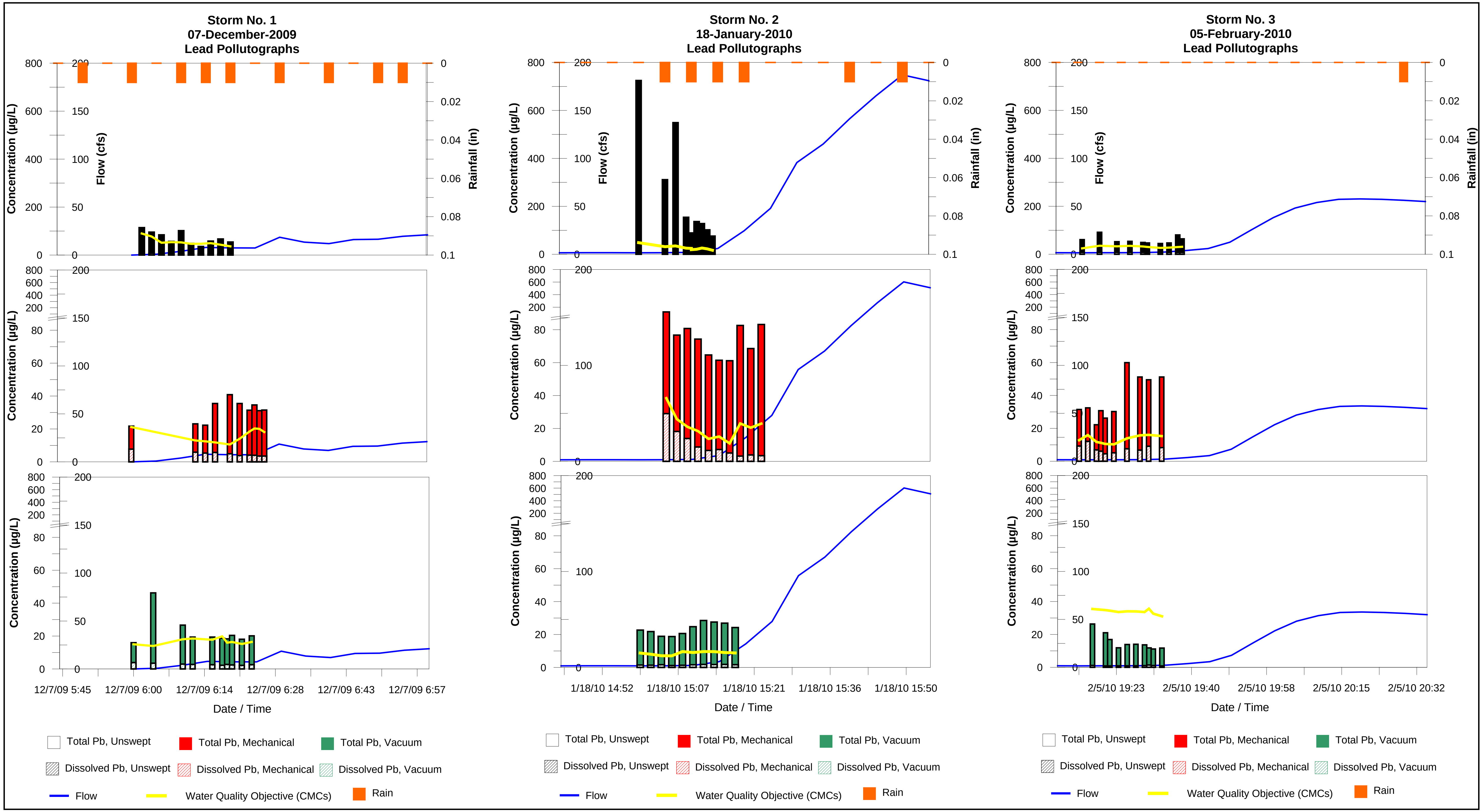

Figure 5-6. Total Lead and Dissolved Lead First Flush Pollutographs for Each Monitored Storm Event

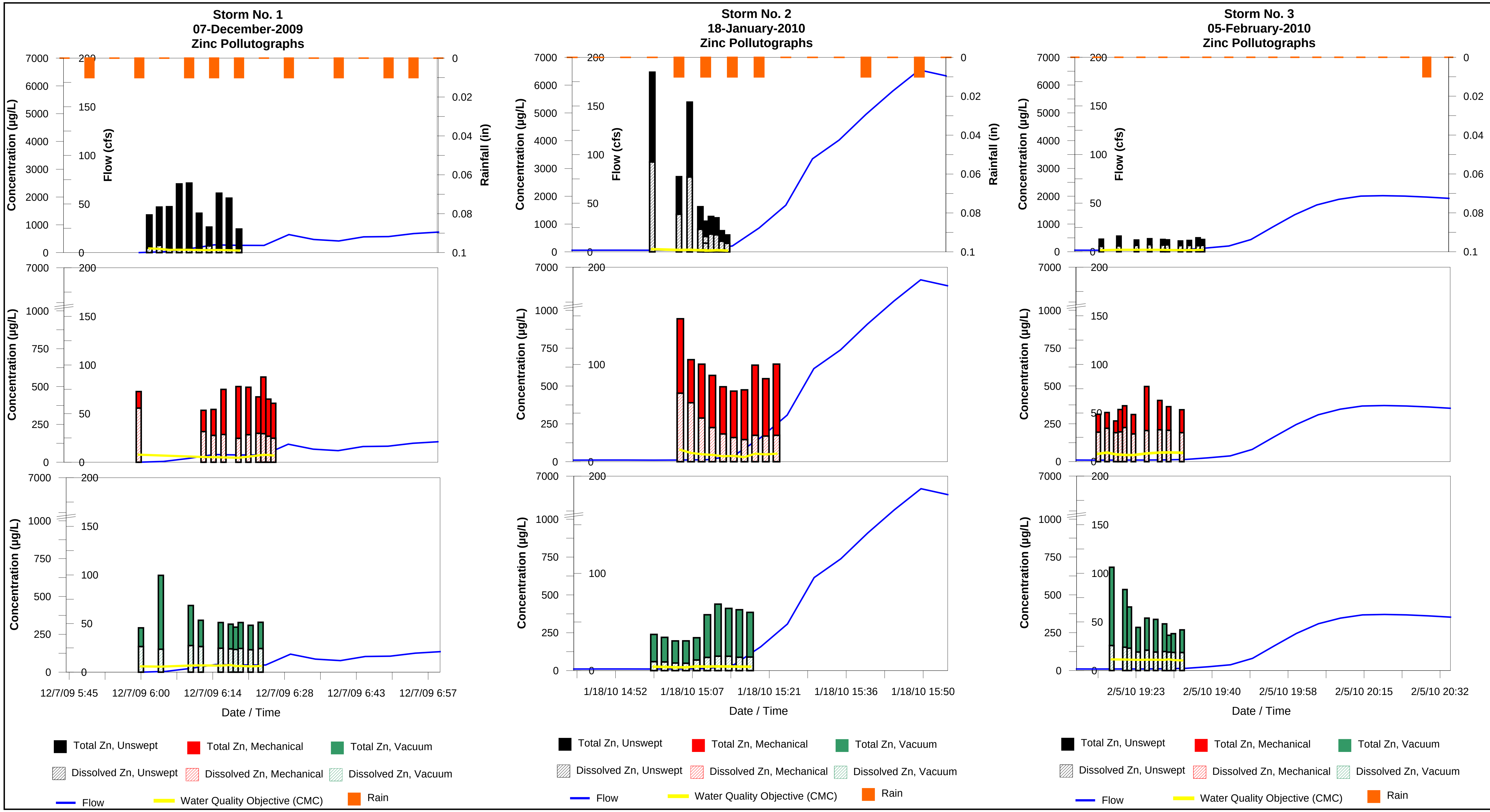

Figure 5-7. Total Zinc and Dissolved Zinc First Flush Pollutographs for Each Monitored Storm Event

5.4 Wet Weather Pyrethroid Results

In addition to TSS and metals, samples during the storm events were also collected and analyzed for synthetic pyrethroids. During each storm event, ten sub-samples were collected and composited for the pyrethroid analyses, resulting in one composite sample per site for each event (nine composite samples overall for the three storms). The results are presented in Figure 5-8 for the pyrethroids that were most commonly detected: Bifenthrin, Cyfluthrin, and Permethrin. Concentrations of all three pyrethroids were variable at the monitored sites, ranging from non-detect to nearly 12,000 nanograms per Liter (ng/L). There were no apparent trends in the data related to the street sweeping treatment and the results suggest that street sweeping had no observable effect on the levels observed in storm water runoff.

Water quality objectives have not been established for synthetic pyrethroids in the Basin Plan. However, they are known to be toxic at very low concentrations. For instance, an LC_{50} (the concentration of a constituent that is lethal to 50% of the test organisms) has been established for Bifenthrin (9.3 ng/L) and Permethrin (21 ng/L). These values are used as benchmarks in the City's storm water runoff monitoring program. Most of the Bifenthrin and Permethrin concentrations monitored in storm water runoff were well above these levels (Figure 5-8).

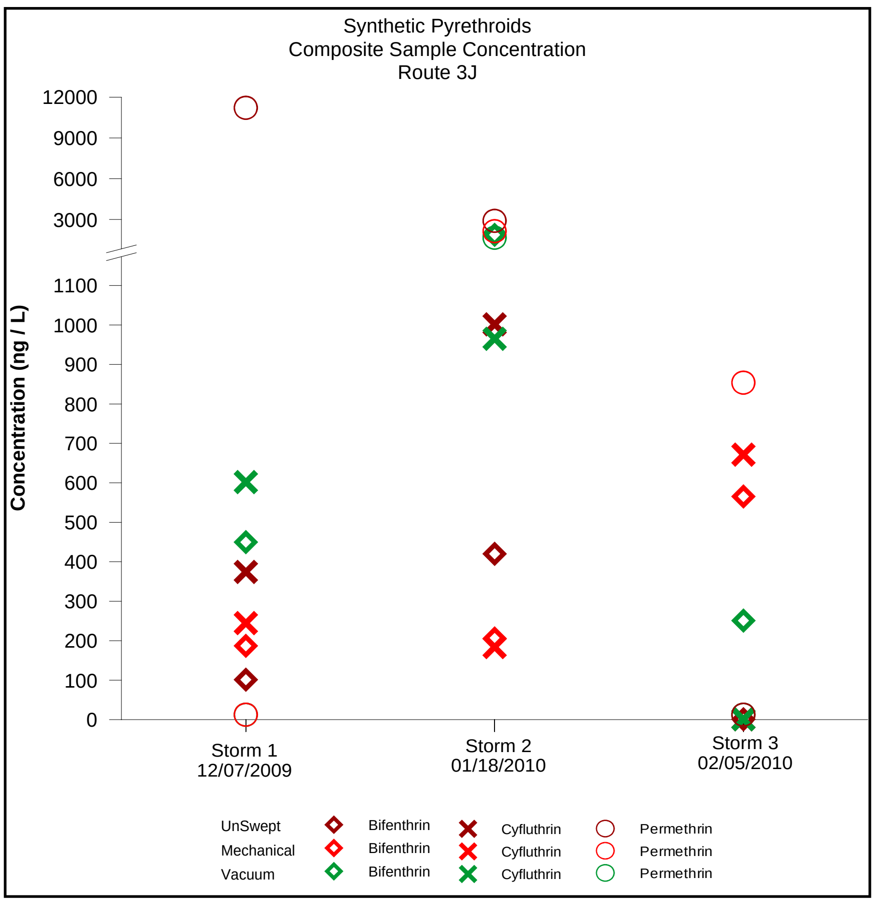

Figure 5-8. Synthetic Pyrethroid Concentrations in Storm Water for Each Monitored Storm Event

5.5 Synthetic Precipitation Leaching Procedure Analysis

The Synthetic Precipitation Leaching Procedure is a laboratory analysis used to evaluate the potential for metals in the dissolved phase to leach from sediment. In this case, street sweeping debris was used with simulated rain water as the leachate. This analysis was intended as a confirmation for field wet weather monitoring results.

An SPLP analysis was completed for each subwatershed for swept debris collected from Route 3J, Route 103 (Figure 5-9), and Routes 617/618. The concentration of total copper, lead, and zinc in the debris along with the concentration of dissolved copper, lead, and zinc in deionized water leached with the debris of various grain-size distributions (per Method 1312) was determined in the laboratory. The output of the study was the quantity of metal leached from debris into the water. This percentage was estimated using the ratio of the average dissolved metal concentration per broom mile versus the average total metal concentration per broom mile for each machine and each study route. The results are presented on Figure 5-10.

Figure 5-9. Eroded Hillsides and Canyon Sediments Deposited on the Street in the La Jolla Shores Area

The results (Figure 5-10) suggest that a greater relative proportion of dissolved metals were leached from sediment samples collected from debris collected from the La Jolla Shores Route 103 with the regenerative air sweeper compared to the other routes. The high dissolved metals fraction may have resulted from larger grain size in samples collected from this area, as discussed in Subsection 3.2. Metals preferentially adhere to smaller sediment particles, particularly those in the silt/clay fractions. In general, the mean grain size of samples collected from La Jolla Shores was larger than that of samples from the Chollas Creek Subwatershed and had a smaller proportion of silts and clays. Thus, the metals may preferentially bind to the sediment collected from the Chollas Creek Subwatershed, resulting in a lower proportion of metals in the dissolved phase as reflected on Figure 5-10. This may also explain the very low proportion of dissolved metals in the samples collected with the vacuum sweeper. The mean grain sizes of these samples were smaller than those collected from samples generated from the mechanical and regenerative-air sweepers. This may have produced a corresponding low proportion of dissolved metals in the vacuum sweeper sample in the SPLP analysis, as the metals bind preferentially to the smaller particles.

In general, these results support the findings of the storm water pollutograph monitoring, which suggested that the dissolved proportion of the total metals in a given sample was influenced by TSS concentration (Subsection 5.1.3). Together, the first flush pollutograph and SPLP results suggest that the proportion of dissolved metals in storm water is influenced by both the amount of sediment in the sample (i.e., TSS concentration) as well as the size of the particles (i.e., grain size) and that the proportion can change depending on the suspended sediment characteristics.

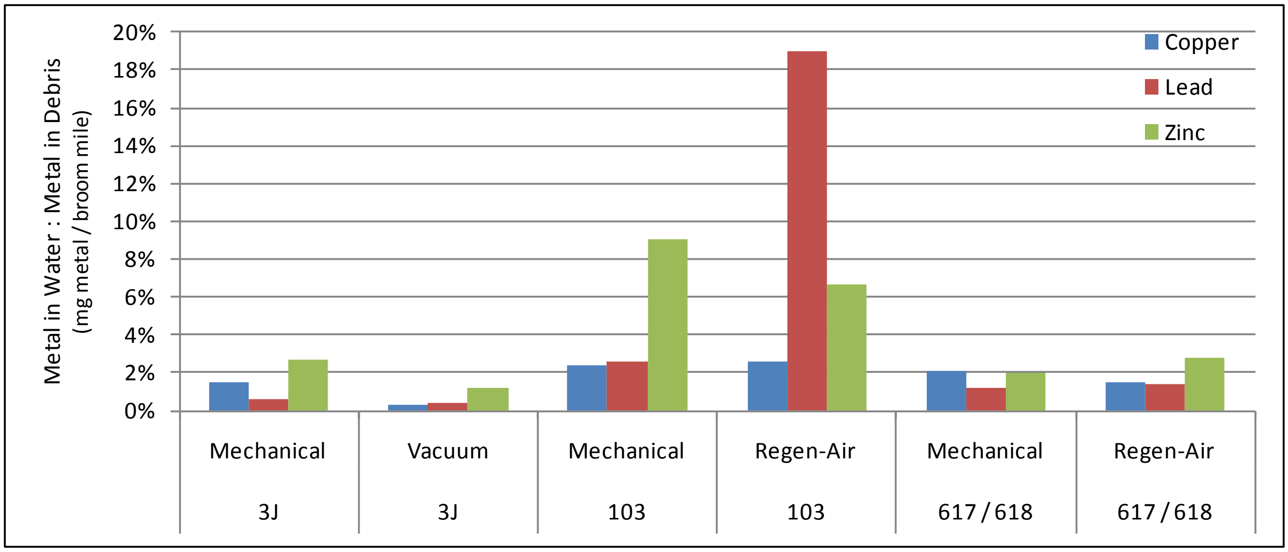

Figure 5-10. Ratios of Dissolved Metal Concentrations to Total Metal Concentrations Determined Using the Synthetic Precipitation Leaching Procedure

6.0 MACHINE EFFECTIVENESS ASSESSMENT ANALYSIS

6.1 Debris Weights

A summary of all of the debris weight data from all four study routes and all machines used on each route is shown on Figure 6-1. The apparent differences in the average pounds of debris per broom mile swept for the four study routes suggest that there are site-specific differences in the ability of street sweeping technology to remove debris from the street surface. Thus, quantifying the baseline condition before implementing targeted aggressive street sweeping will be important for long term load reduction assessments.

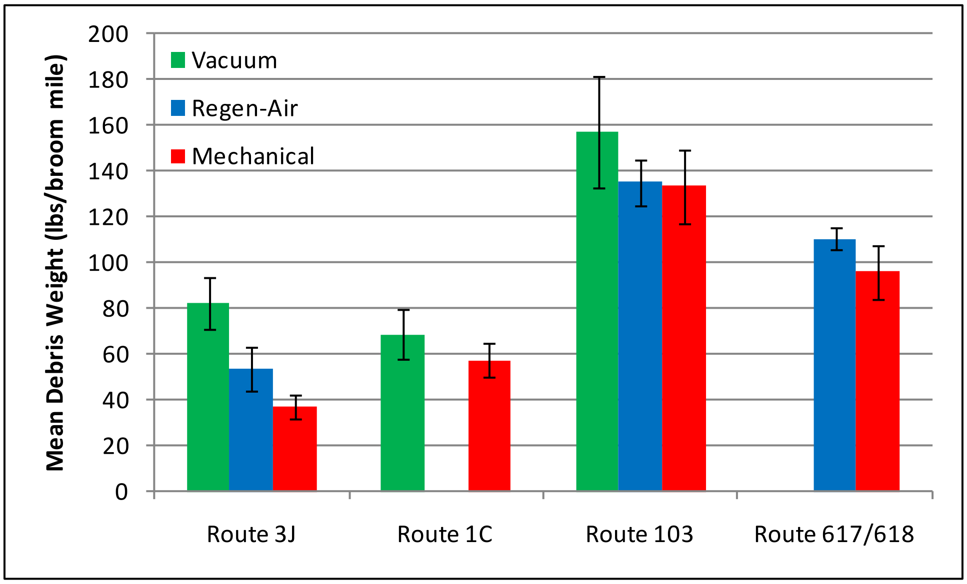

Figure 6-1. Machine Effectiveness by Mean Debris Weight ± Standard Error for All Routes and All Machine Types

As discussed in the route-specific results, and as shown on the stepped bar chart on Figure 6-1, there is a very clear difference in sweeper performance along the relatively flat Route 3J (Chollas Creek Subwatershed). The vacuum sweeper removed 122% more debris than the mechanical sweeper and 52% more than the regenerative-air sweeper. But when significant changes in grade were incorporated into the sweeping route, like along commercial/residential Route 1C and residential Route 103, the vacuum sweeper's performance relative to the other sweepers decreased (similar mean debris weight values and overlapping standard errors). The regenerative-air sweeper also removed a similar amount of debris as the mechanical sweeper in La Jolla Shores Route 103 and Tecolote Creek Route 617/618, and showed to be only marginally more effective than the mechanical sweeper in Chollas Creek Route 3J. Overall, the debris removal results indicate that the vacuum sweeper is more efficient than the mechanical and regenerative-air sweepers, but as indicated by the results for Routes 1C and 103, site-specific differences may affect machine performance.

Both Routes 1C and 103 were hilly routes,[9] located in the same vicinity to the Pacific Coastline of the La Jolla Shores Subwatershed. Along both routes, the vacuum sweeper showed the same relative decrease in effectiveness compared with the other sweepers (contrasting with the apparent differences in performance observed along the relatively flat route in the Chollas Creek Subwatershed). It was concluded that terrain (i.e. steep street grades) impacts the performance of the vacuum sweeper. This conclusion was corroborated by observations made by City operators and the manufacturer. The vacuum and regenerative-air sweepers were designed for and optimally operate on level asphalt surfaces (i.e. airport runways, parking lots, etc). The vacuum system utilized by the vacuum sweeper uses a pressure gradient to suction debris off the street. In order to function, a vacuum sweeper operating on a typical, crowned City street must create a pressure seal between the bottom-side of the machine and the pavement using a well defined curb and gutter. This information was used to identify other factors which would limit sweeper effectiveness and help explain the differences in sweeper performance in the La Jolla Shores Subwatershed relative to the Chollas Creek Subwatershed. As indicated by the manufacturer, the vacuum sweeper's less effective performance along Route 103 is most likely impacted by the lack of a curb and gutter along many of the residential streets and alleys of the route (see Figure 2-4). Both Route 1C and Route 103 have large trees and/or low hanging branches. City sweeper operators indicated that the vacuum sweeper did not perform as well where the street curb line was heavy with branches, sticks, and twigs (Figure 6-2). Many times these areas were re-swept two or three times before the expected removal was attained. A typical note recorded by operators is provided in the daily ticket in Appendix A. Based on this analysis, it was determined that the vacuum sweeper may have a more limited application to relatively flat routes, without large trees hanging over the street, and a well defined curb and gutter. When operated along routes outside of these limiting characteristics, a vacuum sweeper may be prone to more frequent breakdowns and faster wear and tear of the equipment.

Figure 6-2. Sticks and Twigs Can Clog the Vacuum Sweepers and Reduce Performance

6.2 Grain Size

The grain size analysis of the machine effectiveness assessment indicated that sand was the dominant size class for all sweepers in all subwatersheds assessed, but the median size of the particles varied by sweeper type and route. Debris collected in the La Jolla Shores Subwatershed was generally larger than that in the Chollas Creek Subwatershed even when swept with the same machine. In addition, the vacuum sweeper was more efficient at collecting smaller-grain particles (within the sand size class) than the mechanical sweeper in the Chollas Creek Route 3J, but not in La Jolla Shores Route 1C.

[9] Torrey Pines Road, a long, winding major commercial road with several significant changes in slope, constitutes a major portion of Route 1C. There are hills in the eastern and southern portions of Route 103, but not as steep, or long as Torrey Pines Road.

In the La Jolla Shores Route 1C, the similarity among the median grain sizes in the debris collected by the vacuum and mechanical sweepers suggests that the characteristics of the particles on route La Jolla Shores Route 1C may differ from those in Chollas Creek Route 3J. The average median grain size in debris collected from La Jolla Shores Route 1C by the mechanical sweeper was smaller than the debris collected by the mechanical sweeper from Chollas Creek Route 3J. Similar results were observed for the vacuum sweeper debris collected among the two routes, which suggests that the debris on the street in La Jolla may be slightly larger than that found in Chollas Creek.

Alternatively, the vacuum sweeper may be less effective at collecting smaller particles in the La Jolla Shores Route 1C due to characteristics of the route that limit the vacuum sweeper's effectiveness. Visual observations of this route confirm that it is steep in some places and includes multiple, significant changes in street grade. These characteristics may limit the effectiveness of the vacuum sweeper along this route in collecting smaller grain particles. The similarity in the sizes of materials collected by the vacuum and mechanical sweepers in the La Jolla Shores reflect the minimal differences observed between the two sweeper types in debris removal in this subwatershed.

6.3 Debris Chemistry

6.3.1 Site Specific Metals Assessment

The debris chemistry element of the machine effectiveness assessment reflects the site specific differences observed in the debris removal results. In the Chollas Creek Subwatershed, the results suggest that the vacuum sweeper was more effective than the mechanical and regenerative sweepers in removing metals from the street surface. The vacuum sweeper removed 65% more copper than the mechanical sweeper, nearly three times more lead, and 45% more zinc. The regenerative-air sweeper was less effective in removing metals from the street surface than either the mechanical or vacuum sweepers. The results suggest that, in the Chollas Creek Subwatershed, the vacuum sweeper is the most effective of the machines assessed in removing metals from the street surface.

In the La Jolla Shores Subwatershed, the metal loads removed were greater for the vacuum sweeper than the mechanical sweeper. However, these loads are based on the debris removed and the concentrations of the metals in the debris. Since there were only marginal differences between the sweeper types in the total debris removed, the corresponding difference in metals loads was a result of the high copper and zinc concentrations found in the vacuum-swept debris. Indeed, copper and zinc concentrations in the La Jolla Shores vacuum-swept debris for the machine effectiveness assessment were greater than those in any sample collected over the course of the Pilot Study (Appendix G).

It is unclear why metals concentrations would be substantially greater in the vacuum-swept samples in La Jolla Shores. Debris was collected by the mechanical sweeper between April and May, 2009 and by the vacuum sweeper between October and November, 2009. It is unlikely that vehicle traffic, which can apply substantial metal loads to street surfaces, significantly changed between the two monitoring periods. In addition, the difference is not explained by grain size, as the median particle sizes of debris collected by the two machines were also similar. One possible explanation is the large difference in antecedent dry weather days and the presumed differential loading rates between the two monitoring periods. The debris from the mechanical sweeper was collected at the end of the rainy season after the streets had been flushed with storm water, thus reducing metal loads. The vacuum sweeper had been scheduled to sweep immediately after the mechanical sweeper, but machine breakdowns and scheduling difficulties pushed the monitoring date into late October and early November, 2009. Prior to that time, there had been over nine months of dry weather in southern California (the most recent storm relative to the vacuum sweeping collection period in late October was February 27, 2009). This long antecedent dry period prior to the vacuum sweeping may have allowed for a build-up of metals on the road surface that was not present prior to the mechanical sweeper collection period that followed after the rainy season. This may have contributed to the high metals concentrations observed in the vacuum-swept debris.

The debris removal and grain size results suggest little if any differences between the vacuum and mechanical sweepers in their ability to remove debris from the streets along the La Jolla Shores routes. Thus, the high metal loads observed for the vacuum sweeper in this subwatershed do not appear to be a result of more efficient sweeping by the vacuum sweeper, but rather from high concentrations as a result of differing environmental characteristics between the sampling periods. In this way, the interpretation of machine effectiveness generated by the debris removal and grain size data (which showed no difference between the vacuum and mechanical machines) appears to be valid for the La Jolla Shores Subwatershed.

A comparison of the effectiveness of the mechanical and vacuum sweepers in Chollas Creek is summarized in Table 6-1.

Table 6-1. Summary of the Effectiveness of the Mechanical and Vacuum Sweepers in Chollas Creek Route 3J

On average, along Route 3J, the Vacuum Sweeper… [1]		
Swept	122%	more debris than the mechanical.
	46%	smaller particulates than the mechanical.
Removed	65%	more total copper from the street than the mechanical.
	183%	more total lead from the street than the mechanical.
	45%	more total zinc from the street than the mechanical.
Resulting in…	34%	less total copper measured in runoff during the first flush than for the mechanical.
	59%	less total lead measured in runoff during the first flush than for the mechanical.
	26%	less total zinc measured in runoff during the first flush than for the mechanical.
	30%	less dissolved copper measured in runoff during the first flush than for the mechanical.[2]
	76%	less dissolved lead measured in runoff during the first flush than for the mechanical.[2]
	42%	less dissolved zinc measured in runoff during the first flush than for the mechanical.[2]

1. The data collected for the pilot study is preliminary and should not extrapolated for a City-wide program. Additional monitoring and modeling is necessary before larger-scale recommendations can be made.
2. Results are based on the raw water quality data in Appendix G for the mechanical and vacuum sweepers.

7.0 SWEEPING FREQUENCY ASSESSMENT ANALYSIS

The results of the sweeper frequency assessment indicate that there may be some differences between the vacuum and the mechanical sweepers in the amount of debris they can collect at different aggressive sweeping frequencies (e.g., once vs. twice per week). According to the data, aggressive sweeping frequencies did not impact the vacuum sweeper's effectiveness. The vacuum sweeper collected the same amount of debris and metals per broom mile swept at the once and twice per week frequencies (i.e. no diminishing return for the more aggressive frequency). In contrast, the data indicate a point of diminishing returns for the mechanical sweeper. The amount of metals removed per broom mile swept by the mechanical sweeper was the same at both aggressive frequencies (i.e., there were no clear differences in the amount of metals removed per broom mile between the two sweeping frequencies). But, more debris was swept per broom mile at the once per week frequency than at the twice per week frequency.[10]

Based on these results, high frequency aggressive street sweeping may therefore be a viable management tool for reducing loads in a given watershed and may be most beneficial in areas where sediment and/or metals loading is high or the drainage is small enough to allow for a focused effort. When route conditions permit (see Section 6.1), the optimal load reduction may be achieved by the vacuum machine at an aggressive twice per week frequency. Otherwise, the mechanical sweeper may be effectively used at a less aggressive once per week frequency.

The Chollas Creek Subwatershed provides an example of where twice per week sweeping with the vacuum sweeper may provide the most significant reductions in metals loads. Aerial deposition rates of metals have been shown to be high in Priority Sector 1 of the Chollas Creek Subwatershed at the mouth of Chollas Creek, which is in close proximity to several known emission sources (Weston, 2009a). The greatest removal rates of metals from street sweeping would likely be achieved in this area due to the high rates of aerial deposition. However, the gains made in load reduction with twice per week sweeping would need to be weighed against managerial constraints, such as budget effects, scheduling, and concerns of residents in the watershed.

[10] To describe this phenomenon another way, the amount of debris on the street available for collection and actually swept up by the vacuum sweeper on a Tuesday (the first day of sweeping at the twice per week frequency) was equal to the amount of debris available and swept up by the vacuum sweeper on Thursday (the second day of sweeping at the twice per week frequency). In contrast, the mechanical sweeper swept “less” debris on Tuesday than the vacuum sweeper (see machine effectiveness assessment results) AND swept even less debris on Thursday.

8.0 WATER QUALITY ANALYSIS

The results of the water quality assessment indicate that street sweeping is an effective BMP for reducing the concentrations of TSS and metals in storm water runoff. The reduction in constituent concentrations varied by the storm event, but overall the mean TSS concentration in the vacuum-swept street segment was one seventh of that from the unswept street and half of the mean concentration from the street segment swept by the mechanical sweeper. Substantial reductions were also observed for total and dissolved metals, which suggests that the street sweeping provides an effective means of reducing concentrations of some constituents in storm water runoff and that the vacuum sweeper is more effective in reducing storm water constituent concentrations than the mechanical sweeper.

The purpose of this element of the study was to answer Study Question #3:

> **Is there a quantifiable link between aggressive street sweeping and the reduction of metals and other constituents of concern in storm water runoff?**

Table 8-1 compares the constituent concentrations observed along the mechanical swept and vacuum swept portions of Meade Avenue to the concentrations observed along McClintock Street (i.e. the "unswept" condition). These results are also depicted graphically in Figure 5-3 through Figure 5-7. It is important to note that the water quality element of this study was based on pollutographs conducted during the first flush of three storm events. Maximal concentrations of several constituents are often observed during the first flush of the storm as the storm flows first begin to mobilize material that has been deposited on the street surface. Thus, the lower storm water concentrations of TSS and metals in the vacuum- and mechanically-swept street segments compared to the "unswept" street likely represents maximal reductions relative to an entire storm event. In addition, the samples collected in the street gutter may not be entirely reflective of conditions in the receiving water. Additional monitoring will be required to determine if these levels of constituent reductions observed in the pilot study can be maintained over the course of a storm event.

Table 8-1. Potential Improvement to Water Quality due to Aggressive Street Sweeping on Chollas Creek Route 3J

On average, aggressive street sweeping with the Mechanical Sweeper (once per week) resulted in… [1, 2, 3]	
56%	less total copper measured in runoff during the first flush than for the "unswept" street.
60%	less total lead measured in runoff during the first flush than for the "unswept" street.
58%	less total zinc measured in runoff during the first flush than for the "unswept" street.
74%	less total suspended solids measured in runoff during the first flush than for the "unswept" street.
19%	less dissolved copper measured in runoff during the first flush than for the "unswept" street.
35%	more dissolved lead measured in runoff during the first flush than for the "unswept" street. [4]
23%	more dissolved zinc measured in runoff during the first flush than for the "unswept" street. [4]

Table 8-1. Potential Improvement to Water Quality due to Aggressive Street Sweeping on Chollas Creek Route 3J

On average, aggressive street sweeping with the Vacuum Sweeper (once per week) resulted in… [1, 2, 3]	
71%	less total copper measured in runoff during the first flush than for the "unswept" street.
83%	less total lead measured in runoff during the first flush than for the "unswept" street.
69%	less total zinc measured in runoff during the first flush than for the "unswept" street.
85%	less total suspended solids measured in runoff during the first flush than for the "unswept" street.
43%	less dissolved copper measured in runoff during the first flush than for the "unswept" street.
67%	less dissolved lead measured in runoff during the first flush than for the "unswept" street.
29%	less dissolved zinc measured in runoff during the first flush than for the "unswept" street.

1. The analyzed wet weather monitoring data only represents the first flush of runoff for three storm events monitored during the 2008-2009 Monitoring Season along streets in the northwestern portion of the Chollas Creek Subwatershed. This data is preliminary and should not extrapolated for a City-wide program. Additional monitoring and modeling is necessary before larger-scale recommendations can be made.
2. Results are based on the raw water quality data in Appendix G for the mechanical and vacuum sweepers and the "unswept" street (i.e. McClintock Street).
3. The "unswept" street is actually swept with the mechanical sweeper once every two months. This represents the City's standard practice in residential neighborhood and therefore the "baseline" from which residential sweeping could be increased.
4. The dissolved metals fraction is related to the sediment content of water. The varying load reductions for the dissolved metals fraction may be due to sample specific variations of sediments.

9.0 EDUCATION AND OUTREACH DISCUSSION

The City has been conducting a survey of both commercial businesses and residents in each of the three subwatersheds where the Targeted Aggressive Street Sweeping Pilot Study was implemented. The results from this survey are currently under analysis and the findings will be incorporated into any overall programmatic recommendations (Action Research Inc., 2010).

10.0 CONCLUSIONS

The Targeted Aggressive Street Sweeping Pilot Study was designed to answer three study questions related to machine type effectiveness, sweeping frequency effectiveness, and links to water quality. By answering these questions, the City will be able to optimize the effectiveness of their street sweeping operations and begin assessing the combination of different watershed activities in the City's overall watershed protection strategy. The results of the study are summarized below by study question.

1. **Which sweeping machine (i.e., mechanical, regenerative-air, or vacuum) is most effective in removing metals and other constituents of concern?**

For Chollas Creek Route 3J, the vacuum sweeper was more effective than the regenerative air and mechanical sweeper in removing metals from the street surface. In this subwatershed, the vacuum sweeper removed an average of 82.1 pounds per broom mile compared to 54.0 pounds per broom mile for the regenerative are sweeper and 37.1 pounds per broom mile for the mechanical sweeper. Although the amount of debris removed per broom mile was variable from week to week for each machine, the results from Route 3J suggest that the vacuum machine removed, on average, more than twice as much debris as the mechanical machine (121%) and 52% more debris than the regenerative air machine. The greater debris removal efficiency of the vacuum sweeper was also reflected in the amount of metals removed per broom mile. The vacuum sweeper removed 65% more copper than the mechanical machine, nearly three times as much lead, and 45% more zinc. Thus, the results suggest that the vacuum sweeper is the most effective of the three machines assessed in removing debris from the street surface in Chollas Creek Route 3J.

In contrast to the machine comparison results in the Chollas Creek Subwatershed, the vacuum sweeper performed only marginally better than the mechanical sweeper in La Jolla Route 1C. The vacuum sweeper in La Jolla Route 1C removed an average of 68.6 pounds of debris per broom mile compared to 57.3 pounds per broom mile removed by the mechanical sweeper; a gain of approximately 20%. Similar results were observed in La Jolla Route 103. The La Jolla Shores routes are characterized by hilly terrain, steep slopes, degraded road surfaces in some areas, and overhanging trees that deposit debris to the street. These site specific characteristics (i.e. terrain, presence of a well defined curb and gutter, vegetation, etc.) may have limited the effectiveness of the vacuum sweeper along the La Jolla Shores routes, resulting in the marginally enhanced effectiveness compared to the mechanical sweeper.

2. **Is it more efficient and effective to aggressively sweep at a high frequency (e.g., once a week or twice a week)?**

The results of the sweeper frequency assessment indicate that the vacuum sweeper collected the same amount of debris per broom mile swept from Chollas Creek Route 3J, whether it was used once or twice per week. The chemistry results from the vacuum-swept debris reflect this observation, as there were no clear differences in metals concentrations per broom mile between the two machines. Thus, with a vacuum sweeper, there is no loss of efficiency in debris and metals removal with a more aggressive sweeping frequency. Sweeping a street twice per week with the vacuum sweeper would remove twice as much debris and metal as sweeping once per week. Furthermore, sweeping twice per week with the vacuum sweeper would likely be a useful tool for reducing loads in a watershed or drainage area that has a high potential for sediment and/or metals loading. However, the benefits of sweeping twice per week in reducing metals loads would have to be weighed against the costs associated with aggressive sweeping frequency, such as: scheduling, budgets, sign postings, and potential resistance from home owners and businesses within the sweeping route.

In contrast to the sweeping frequency assessment results for the vacuum machine, the mechanical sweeper removed more debris per broom mile at a frequency of once per week compared to a frequency of twice per week. These results suggest there is a loss in efficiency with the mechanical sweeper with the more aggressive of the two sweeping frequencies studied, and that that sweeping twice per week would not produce twice the debris as sweeping once per week. These results were at odds with the chemistry results from this comparison, which showed no clear differences in the amount of metals removed per broom mile between the two aggressive sweeping frequencies. Thus, in terms of management, using the mechanical machine at a twice per week frequency may result in marginally higher load reductions that may not be as efficient as using the vacuum machine at the accelerated rate and would most likely be offset by the increased cost associated with aggressive sweeping.

3. Is there a quantifiable link between aggressive street sweeping and the reduction of metals and other constituents of concern in storm water runoff?

This study question was answered by comparing the effectiveness of the mechanical and vacuum sweepers in debris and metals removal and the corresponding reduction in copper, lead, and zinc in storm water runoff. Route 3J was used for the comparison because it was the only route that encompassed water quality with the other study elements. The results of this analysis demonstrate that there is a link between metals removal by street vacuum and mechanical sweepers and the associated reduction in metals concentration in storm water runoff. Specifically, the mechanical sweeper at a frequency of once per week on Chollas Creek Route 3J, removed 1.04 g/broom mile of total copper, which resulted in a 56% reduction in total copper concentrations in storm water runoff compared to the unswept street. Using the same parameters, the vacuum sweeper produced a 71% reduction of total copper in storm water runoff compared to the unswept street. Similar reductions were seen for total lead and total zinc. The results suggest that removal of constituents from the street surface via sweeping results in substantial reductions the concentrations of those constituents in storm water runoff. This link is dependent on the constituent being assessed and the type of sweeper employed.

The lower storm water concentrations of TSS and metals in the vacuum-swept street and mechanically-swept streets compared to the unswept street likely represents maximal reductions relative to an entire storm event. In addition, the samples collected in the street gutter may not be entirely reflective of conditions in the receiving water. Therefore, additional monitoring will be required to determine if these levels of constituent reductions observed in the pilot study can be maintained over the course of a storm event.

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