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### EFFECTIVENES OF STREET SWEEPING IN STORMWATER POLLUTION SOURCE CONTROL

Interim Report

Q. Rochfort, K. Exall, J. Marsalek, J. P'ng, V. Shi,  
V. Stevanovic-Briatico and S. Kok

WSTD Technical Note No. AEMR-TN07-002

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# **Effectiveness of Street Sweeping in Stormwater Pollution Source Control**

## **Interim Report**

**(Summary of the 2004 & 2005 Field Seasons,  
Markham Road, Toronto)**

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**January 5, 2007**

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NWRI TN # 07 - 002

## ABSTRACT

The effectiveness of street sweeping as a pollution source control measure improving stormwater quality was tested at a site in Scarborough (Toronto). Three types of sweeper were tested: an old model regenerative air, a conventional mechanical and a new-technology regenerative air. The test site along Markham Road (Scarborough) was characterized by a traffic volume of 26,000 vehicles / day. A paired-plot experimental design was employed; one plot (~ 50 m between two catchbasins) along the curb lane was swept by the selected sweeper and the following plot was left unswept. Sampling occurred immediately after the sweeper had passed. Wet samples were obtained by washing off a 20 m section of curb lane (80 m<sup>2</sup>) and dry samples were collected using an industrial vacuum cleaner over a similar 80 m<sup>2</sup> area. A total of 18 pairs (swept / unswept) of wet samples and 13 pairs of dry samples were collected during the 2004 and 2005 field seasons. Differences in samples from swept (treated) and unswept (untreated) plots were assessed by measuring the following parameters: (a) toxicity, conventional water quality parameters, and particle sizes in wet samples, and (b) conventional sediment quality parameters, total residue mass, and particle sizes for dry samples. The results from both wet and dry sampling were highly variable and only one-third of the paired comparisons were statistically significant; in some instances showing measurable improvements between unswept and swept and at other times no improvement or even a worsening. Analysis of the data collected so far indicates that the new regenerative air sweeper provided the greatest environmental benefits by reducing the total mass of road deposited sediment after sweeping (the mean particle size of solids was also reduced) and some dissolved metals in runoff (e.g., Zn). Such benefits may be offset by increased capital costs of sweeping with this type of high-efficiency PM<sub>10</sub> sweeper.

## RÉSUMÉ

L'efficacité du balayage des rues comme mesure de contrôle des sources de pollution améliorant la qualité des eaux de ruissellement a été testée à un site de Scarborough (Toronto). On a utilisé trois types de balayeuse : un ancien aspirateur régénératif, une balayeuse mécanique courante et un aspirateur régénératif de nouvelle technologie. Le site d'essai le long de Markham Road (Scarborough) était caractérisé par un volume de circulation de 26 000 véhicules/jour. On a utilisé une configuration d'expérience à parcelles appariées; l'une des parcelles (~ 50 m entre deux bassins hydrologiques) le long de la voie en bordure a été balayée par la balayeuse choisie et l'autre parcelle n'a pas été balayée. On a prélevé des échantillons immédiatement après le passage de la balayeuse. On a obtenu des échantillons humides en lavant une section de 20 m de la voie en bordure (80 m<sup>2</sup>) et on a recueilli des échantillons secs en utilisant un aspirateur industriel sur une section similaire de 80 m<sup>2</sup>. On a recueilli en tout 18 paires (parcelles balayées / parcelles non balayées) d'échantillons humides et 13 paires d'échantillons secs au cours des saisons 2004 et 2005. On a évalué les différences des échantillons provenant des parcelles balayées (traitées) et non balayées (non traitées) en mesurant les paramètres suivants : a) la toxicité, les paramètres courants de qualité de l'eau et les tailles des particules dans les échantillons humides, et b) les paramètres courants de qualité des sédiments, la masse totale des résidus et la taille des particules dans les échantillons secs. Les résultats pour les échantillons humides comme pour les échantillons secs sont très variables et seulement un tiers des comparaisons de parcelles appariées est statistiquement significatif, montrant parfois des améliorations mesurables entre les parcelles non balayées et les parcelles balayées, et parfois aucune amélioration ou même une dégradation. L'analyse des données recueillies jusqu'ici indique que le nouvel aspirateur régénératif offre les meilleurs avantages environnementaux en réduisant la masse totale des sédiments qui restent sur la chaussée après le balayage (la taille moyenne des particules solides est également réduite) et celle des métaux dissous dans les eaux de ruissellement (p. ex., Zn). Ces avantages peuvent être atténués par une augmentation des coûts d'investissement pour le balayage avec ce type de balayeuse à grande efficacité pour PM<sub>10</sub>.

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# 1 INTRODUCTION

## 1.1 Street Sweeping as a Method of Stormwater Source Control

The concept of stormwater pollution was originally based on the principle of pollutant accumulation on urban surfaces during dry weather and the washoff of such pollutants (as urban runoff) during wet weather (FWPCA, 1969). Recent findings indicate additional sources of pollution, such as air scavenging, soluble pollutants, corrosion and erosion of urban surfaces, spills, and applications of deicers and anti-skid materials. The mechanism of pollutant accumulation and washoff suggests that if such accumulations are reduced by street cleaning prior to rain, fewer solids and associated contaminants would be available to enter receiving waters. Thus, street cleaning appeared to be a possible source control method for enhancing stormwater quality.

Even though street cleaning (mostly done by mechanical sweeping) undoubtedly removes significant quantities of various materials and chemicals from street surfaces, the benefits of improved stormwater quality are hard to prove, and the evidence offered in the literature is generally inconclusive. The early version of the U.S. EPA Stormwater Management Model (USEPA, 1971) assumed user-specified removals of pollutants by sweeping, and the model simulated improvements in stormwater quality arising from this reduced pollutant input. This concept was confirmed by Malmqvist's studies in Sweden (1978), who in limited studies found street sweeping effective in improving stormwater quality. Much broader field assessments of street sweeping were conducted under the U.S. Nationwide Urban Runoff Program (NURP) in a number of cities, and with the street cleaning equipment available at that time (in the early 1980s); no statistically significant reductions in stormwater pollution were found. Comparisons of swept and unswept conditions indicated both increases and reductions in constituents in stormwater runoff from these areas, and none of the reductions was greater than 50%. Thus, the final NURP report concluded that the hypothesis that stormwater quality is improved by street sweeping is not generally supported by the collected field data, even though it could occur in isolated, site specific cases (USEPA, 1983).

The negative assessment of street sweeping prevailed until 1997, when new information on street sweeping was published by Sutherland and Jelen (1997 and 1998), who reported that the NURP conclusions do not apply to modern sweepers effective in picking up the smallest particles. Their study was conducted on port docks, with an operation somewhat different from city streets. The extrapolation of their data by modelling indicated that biweekly sweeping could reduce annual pollutant loads of TSS, TP, TPb, TZn and TCu by 20-60%. In particular, the components that can dissolve during rain events could potentially be (partly) removed by street sweeping, therefore reducing the load to receiving waters. Typical stormwater facilities do not deal with such soluble contaminants, hence street sweeping could be an effective way to deal with soluble contaminants in stormwater. Similar findings were published by German and Svensson (2001), who reported on removals of solids and some heavy metals by street sweeping and noted that although the highest concentration of heavy metals was in the finest size fractions, the largest total burdens (proportion by weight) of heavy metals were in the



most plentiful coarse fraction. They found that sweeping reduced the total sediment load, and left the finer-grained particles remaining on the street. The WEF/ASCE Manual on Urban Runoff Quality Management (1998) discussed street cleaning as a source control measure and developed specific recommendations – to be effective, this approach must (a) Prioritize street cleaning with the most sophisticated sweepers, at the highest frequency, and in areas with the highest pollutant loadings, (b) Optimize cleaning frequency based on rainstorm inter-event times, (c) Increase sweeping frequency prior to rain, (d) Maintain the equipment well, and (e) Keep track of cleaning operations to evaluate the street cleaning program. Examples of effective programs include those in some Californian cities, where cleaning is done daily in commercial areas, weekly in residential areas, using vacuum sweepers as much as possible (CASQA, 2003). The Ontario Ministry of Environment (MOE, 2001) supported the conclusions of the WEF/ASCE (1998) and included the above recommendations in their stormwater management fact sheets found in the Stormwater Pollution Prevention Handbook.

Thus, it appeared desirable to revisit the issues of street sweeping and its effect on stormwater quality. In these investigations, the most modern street cleaning equipment (with vacuum action) should be used and they should focus on sensitive evaluations of the stormwater quality, best by its toxicity with limited chemical characterization.

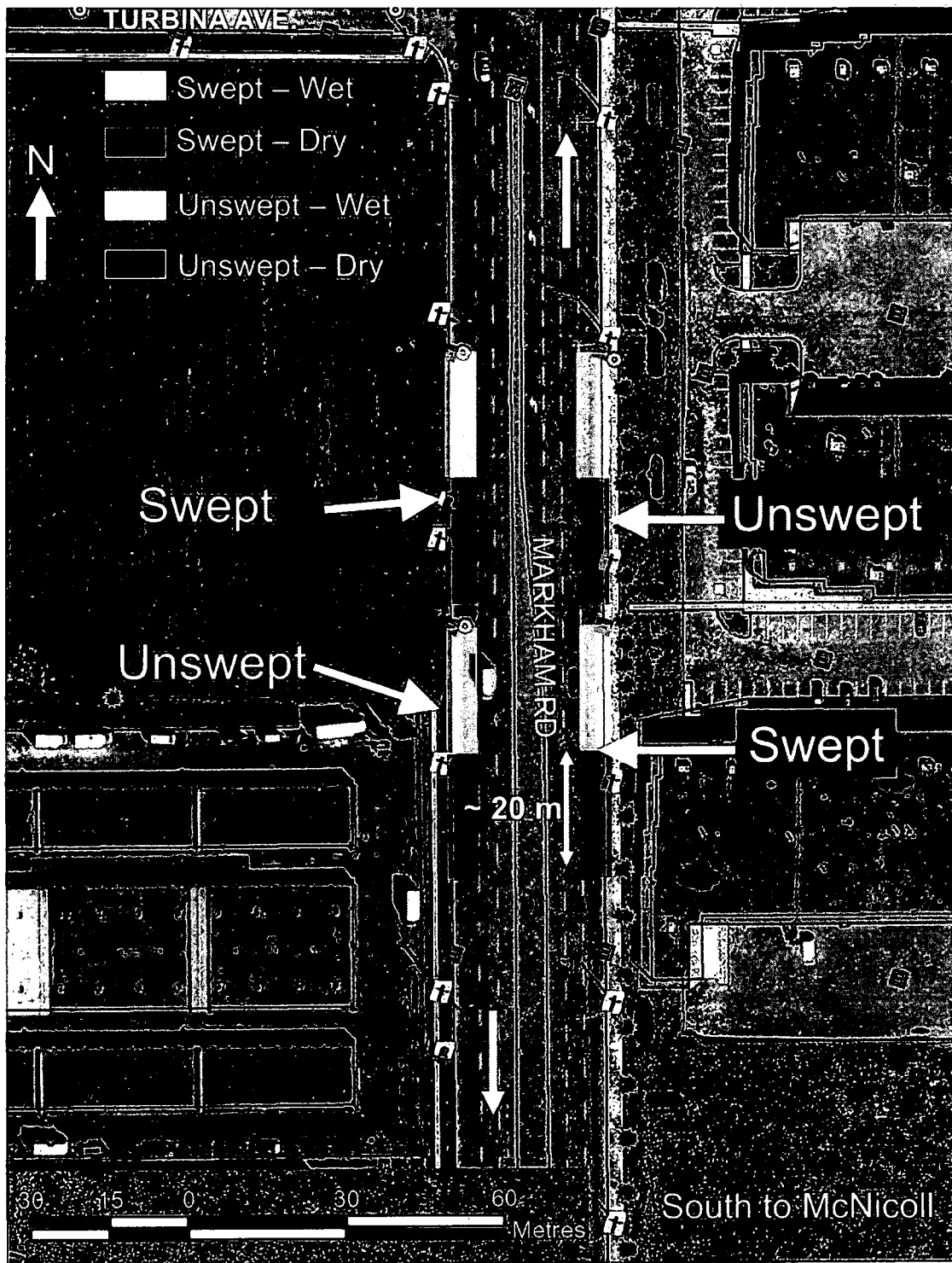
## **1.2 Study Objectives**

This project addressed the effectiveness of street sweeping in stormwater pollution control, in collaboration with two departments of the City of Toronto, Toronto Water (formerly Water and Wastewater Division) and Transportation Services Division. The primary goal of studying street sweeping was defined by the City of Toronto as the assessment of the impacts to local air quality and the health risks posed by fine particulate matter located on the street surface, resuspended by traffic, to the motorist, cyclist and pedestrians travelling along the City of Toronto streets. Such risks could be reduced by efficient street sweeping, which would also produce additional benefits, in the form of improved stormwater quality. This latter benefit then became the primary objective of the study reported herein: to assess the improvement of stormwater quality by street sweeping, which represents one of the source controls included in the Toronto Wet Weather Flow Master Plan. Should street sweeping be found effective in reducing stormwater pollution, it would contribute to the remedial actions in and eventual delisting of the Toronto and Region Area of Concern.

## 2 MATERIALS AND METHODS

### 2.1 Study Area

For the purposes of this study, a single test site (a stretch of roadway away from interfering driveways and intersections) was selected from one of the heavily-traveled major arterial roads in Toronto. When considering potential field sites, the City of Toronto was conducting some "real-world" evaluations of a number of different sweeper types, within the boundaries of Scarborough (District 4). Consequently, the test sweepers were confined to operating within that area, further limiting the choice of potential sites. Several locations were suggested by the City and after site visits and meetings to finalize the study plans, a section of Markham Road just north of McNicoll Avenue was proposed and agreed upon for this study. This site is located in a commercial / industrial area and comprises 3 lanes in each direction, with a total traffic volume of 26,000 vehicles/day. Sub-sections of the curb lanes (delineated by a single catchbasin drainage area) were marked out for "test" (swept) and "reference" (unswept) experimental plots. Swept areas were immediately followed by unswept areas (in the direction of travel), on both the northbound and southbound lanes. This resulted in four test sites being investigated each time: northbound swept (NBSW), northbound unswept (NBUS), southbound swept (SBSW) and southbound unswept (SBUS). The paired reference site was used in each case for comparisons against the swept areas to gauge the effectiveness of the sweepers, since the road dust in the unswept areas could differ slightly, depending on the traffic direction (e.g., construction debris carried into test area). It was more realistic to compare sites which were adjacent to each other and would have similar traffic conditions. Within each of these four catchbasin drainage areas, the area was further subdivided into "wet" and "dry" sampling locations; wet sampling occurred over the area nearest the catchbasin and dry sampling occurred furthest away. An aerial photograph (Figure 2.1) shows the locations for each of the testing areas. The road drainage slopes to the north and reaches its lowest point near Turbina Avenue. Normal City of Toronto operations would require this site to be swept once per week and at a speed of 8-15 km/h, using a conventional mechanical sweeper, however, no sweeping took place during test periods, so that the solids could build up on the road surface.



**Figure 2.1:** Markham Road site paired test catchment areas

## **2.2 Street Sweepers Employed**

Three different types of street sweeper were used between July and November over a two-year period (2004 and 2005): an old-technology regenerative air sweeper (ORA - see Figure 2.2), a conventional mechanical sweeper (CM - see Figure 2.3) and a new-technology regenerative air sweeper (NRA - see Figure 2.4). In 2004, two types of street sweeper were tested; one sweeper (an old regenerative air sweeper) was assigned to clean the northbound lanes and the other sweeper (a conventional mechanical sweeper) was assigned to clean the southbound lanes. In 2005, only one type of street sweeper (a new-technology regenerative air sweeper) was evaluated, so it was used to clean both the northbound and southbound lanes, which doubled the number of test results.

The old-technology regenerative air (ORA) sweeper employs a high-velocity turbine fan and pickup head to apply a vacuum suction to the road surface. It lifts the sweepings into the hopper using this vacuum action. This sweeper uses steel gutter brooms to remove compacted debris from the curbs into the pickup head path and water jets are sprayed onto the gutter brooms to suppress dust. Sweeping speeds are between 8-15 km/h depending upon operational conditions.

The conventional mechanical (CM) sweeper uses a large counter-rotating main broom and gutter brooms to sweep road debris into a conveyer system which transports debris into the hopper. Water sprays are used to control dust generated by the gutter brooms and the main broom. Sweeping speeds are 8-15 km/h depending upon operational conditions.

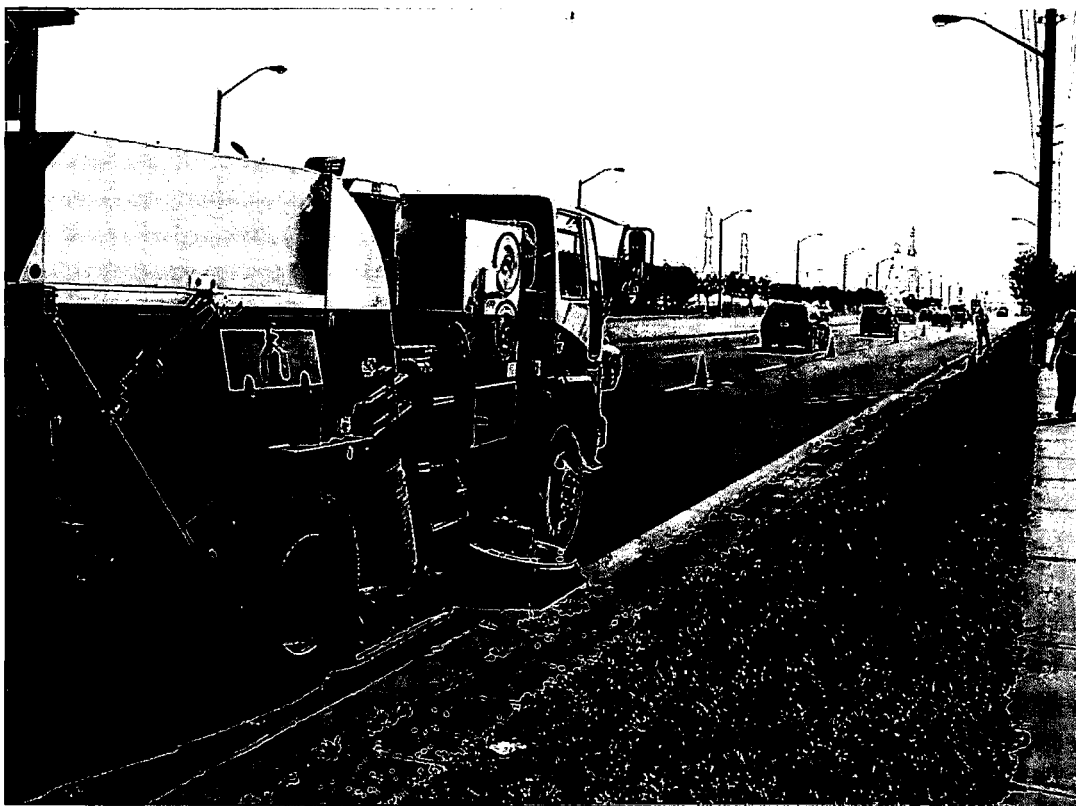
The new-technology regenerative air (NRA) sweeper employs a technology which re-uses air in a closed loop system that both blasts air under pressure (to dislodge sweepings from crevices or cracks) and applies vacuum suction to lift the sweepings. The sweepings are then collected and transferred pneumatically from the pavement surface into a collection hopper, and air containing the fine road dust (particulate matter) is cleaned by filtering. This limits the fine road dust from being redistributed into the ambient air environment. The regenerative-air sweeper utilizes water jets forward of the gutter brooms to suppress the dust when the gutter brooms are moving compacted debris from the curbs to the pickup head path. The closed-loop air regenerative system includes the hopper, screens, centrifugal dust separator and centrifugal fan. The powerful centrifugal fan (driven by an auxiliary engine), blasts air across the pickup head forcing the debris off the pavement and into the vacuum driven stream of air, which deposits debris into the hopper. The screens, centrifugal separator and dry dust filtration system (equipped with a self-cleaning function), clean the air before returning it to the blower to repeat the process. Sweeping speeds are between 5-8 km/h depending upon operational conditions.



**Figure 2.2: Old-technology regenerative air (ORA) sweeper**



**Figure 2.3: Conventional mechanical (CM) sweeper**



**Figure 2.4:** New-technology regenerative air (NRA) sweeper

### **2.3 Field Sample Collection Methods**

During the testing period (August to November), the field site was not swept or washed by City Works vehicles except as directed during site visits for sample collection. Pollutants and debris were allowed to build up on the road surface during the antecedent dry period. For sweeping effectiveness tests, seven days of dry weather (or more) were preferred, but it was often difficult to meet this requirement (particularly during the 2005 field season). The selection of the antecedent dry period of seven days was based on earlier studies. For example, Sartor et al., (1974) showed that in residential and commercial areas, pollutant buildup generally occurred over the first 3 days and then the accumulations remained relatively constant, with peak accumulations of up to 140 kg/curb km [500 lb/curb mile] over 5 days (28 kg/curb km/d). In industrial areas, buildup was greater and occurred over a longer period (7-8 days) before steady state was reached. The peak accumulations were estimated at up to 340 kg/curb km [1,200 lb/curb mile] (37 kg/curb km/d). Pitt et al. (2004) found that an average rate of accumulation was 9 kg/curb km/d, with a range of 1 to 40 kg/curb km/d for a variety of street types and conditions. Breault et al. (2005) observed an average of 14 kg/curb km/d accumulation rates for a suburban street. The City of Toronto currently sweeps major arterials once per week.

It was concluded that a seven-day period was sufficient to reach a steady state, but recognizing that even after 3 days, pollutant buildup reached fairly high levels. With respect to pollutant removal, it was assumed that small rain events (defined as < 7 mm) would be unlikely to result in significant washoff of pollutants from the road surface and therefore wet days were defined as those with a daily rainfall of 7 mm or greater. However, due to operational constraints imposed by the City and frequently occurring rainy weather during the testing period, the restrictions on sampling had to be somewhat relaxed, with samples collected (in one case) after only 2 days of dry weather. In order to accommodate the City of Toronto concerns regarding traffic disruptions, sampling could only occur between 10:00h and 15:00h, and between Tuesday and Thursday. An initial sampling schedule was developed for scheduling personnel, however, due to weather conditions and availability of equipment and / or personnel, it was revised many times, resulting in fewer sampling events. As an example, a summary of delays encountered in 2005 have been included in Appendix A. The sampling dates and associated antecedent dry periods for two field seasons (2004 and 2005) are presented in Table 2.1.

**Table 2.1:** Sampling schedule for street sweeping indicating antecedent dry conditions and total rainfall accumulation (data were collected from Buttonville airport Environment Canada weather station)

Date	Number of antecedent dry days (with < 1 mm of rainfall)	Number of antecedent dry days (with < 7 mm of rainfall)	Depth of rainfall (mm)
August 24, 2004	11	20	13
September 14, 2004	4	4	24.6
September 23, 2004 <sup>1</sup>	8	8	0
October 7, 2004 <sup>2</sup>	5	10	1
November 10, 2004	6	6	11.6
August 9, 2005	5	5	3.6
August 30, 2005	2	2	10.4
October 4, 2005	4	7	49.8
October 27, 2005	2	4	24.7

<sup>1</sup> – in this case, the street had been cleaned on September 14 and no rainfall had occurred between that date and the sampling date on September 23, 2004.

<sup>2</sup> –in this case, the street had been cleaned on September 23 and only 1 mm of rainfall had occurred between that date and the sampling date on October 7, 2004.

In order to better assess and understand the effectiveness of the street sweepers, both wet and dry samples were collected. Figure 2.5 provides an overview of parameters sampled and methods used. Detailed descriptions follow.

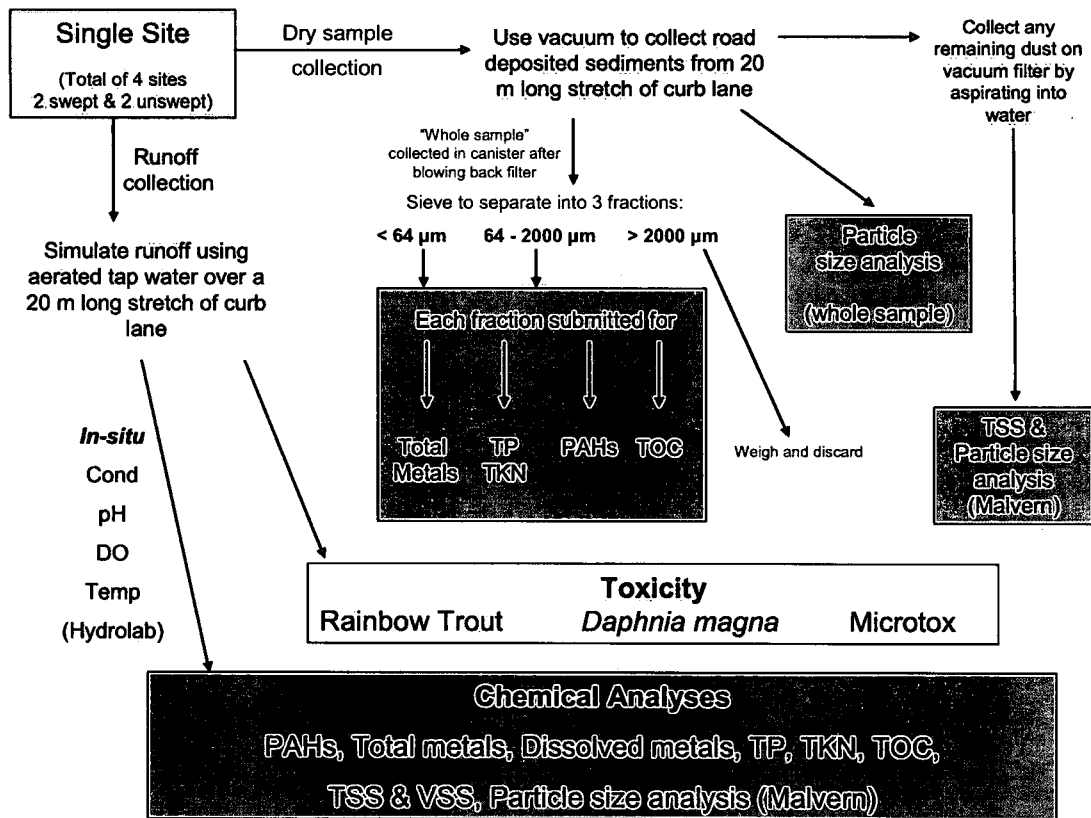


Figure 2.5: Overview of sampling procedure and analyses

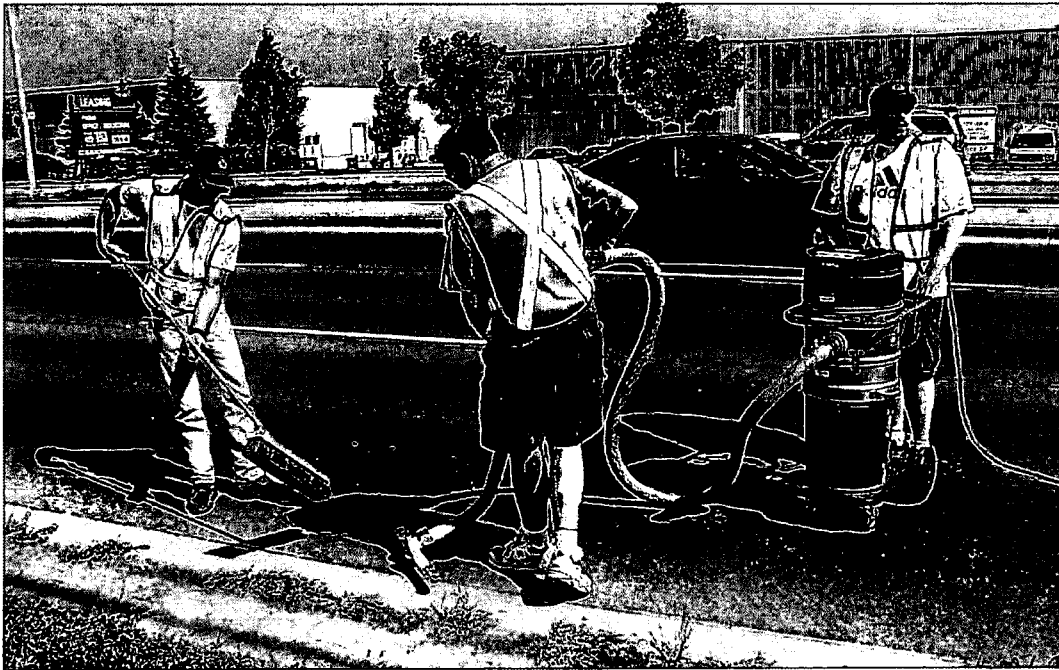
### 2.3.1 Dry sampling

For each test site, the dry sampling was initiated prior to the wet sampling (where possible) to ensure the best surface for dry vacuuming (i.e., the area was as “undisturbed” and as dry as possible). Only the curb lane was sampled, since studies have shown that almost all road deposited sediment and litter accumulate within 1 m of the curb (Novotny, 2003). An area of pavement, 20 m in length by 4 m in width (the width of the curb lane), which was furthest away from the test catchbasin was brushed and vacuumed with a powerful industrial vacuum (Nilfisk-Advance 2050 - constructed of stainless steel), to collect a sample of the road deposited sediment. The broom was moved back and forth gently in front of the vacuum head to loosen any attached fine particles. The vacuum head was moved from the curb to the road crown in overlapping strokes; each pass was overlapped by one-half the width of the vacuum head each time. The vacuum head was also run along the curb to collect material retained in the corners. Total sampling time was 20 minutes, so this allowed the operator to pace the collection of the sample and maintain the same technique in each case.

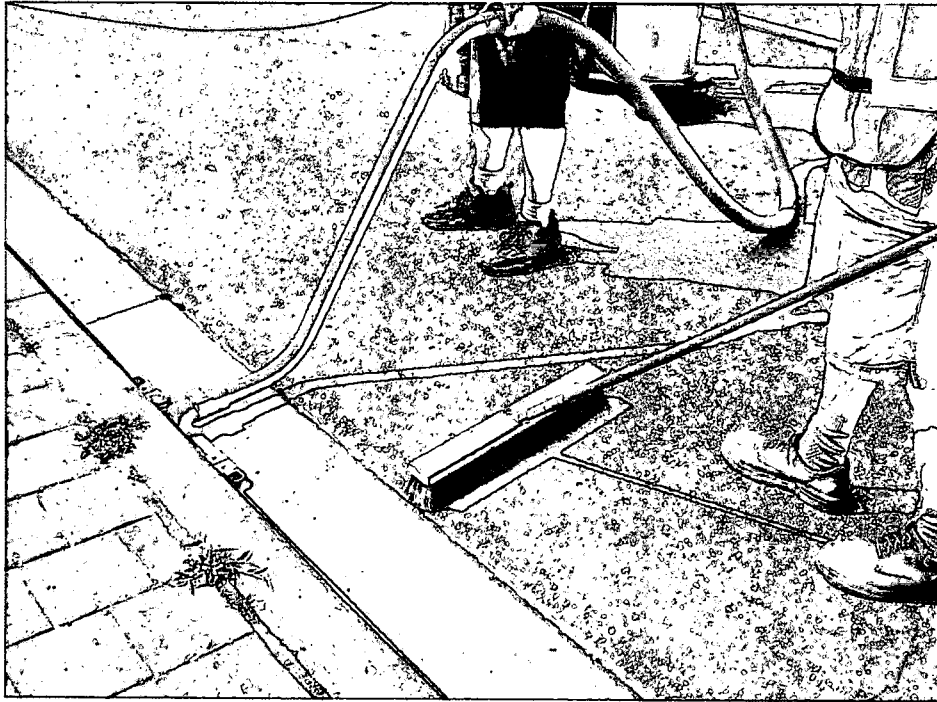
Figures 2.6 and 2.7 show the road deposited sediment sample collection being performed in the field and Figure 2.8 shows the resulting sample being weighed back in the lab. Dry



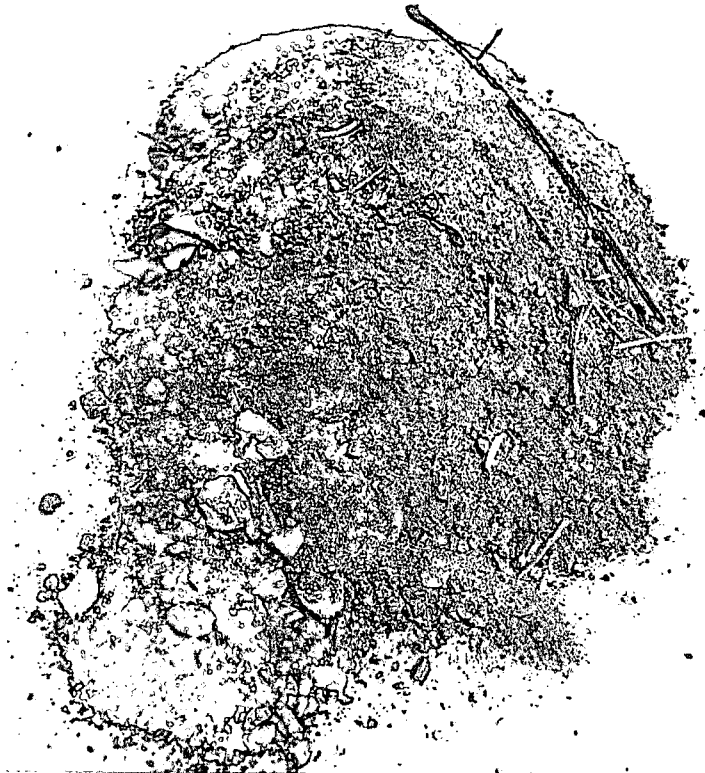
sampling methods remained the same for both years, but in 2004, only one filter was available, so it had to be cleaned in the field, and due to time constraints, this allowed only one side of the street (i.e., northbound or southbound lanes), to be sampled during the site visit. In 2005, four filters were available and were replaced each time a new sample was collected. Since this was the case, the vacuum could be prepared for the next sample relatively quickly, and all four sites could be sampled each time the site was visited. This served to increase the number of solid samples collected in 2005. The solids which remained on the 3  $\mu\text{m}$  filter pleats were carefully vacuumed off through a series of two flasks, each filled with 1L of distilled water (Figures 2.9 and 2.10). This allowed the determination of the total mass of fine solids adhering to the filter (via a total solids test), and preparing the sample for further analysis using the Malvern laser particle size analyzer (limit of detection < 2.9  $\mu\text{m}$ ). Compressed air was used to clear any dust remaining on the filter before reuse.



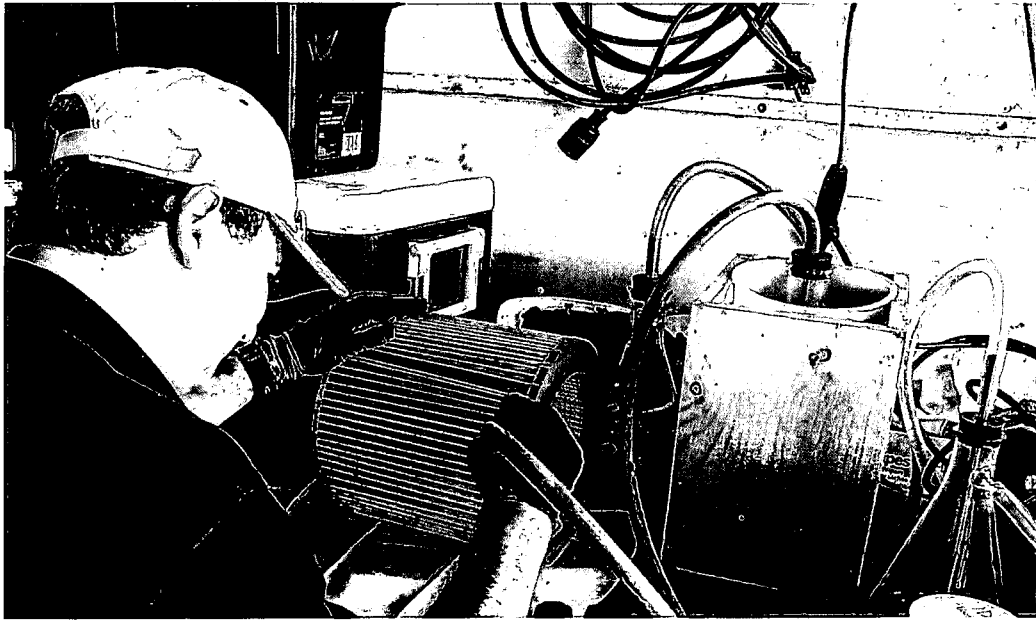
**Figure 2.6:** Road deposited sediment sample collection



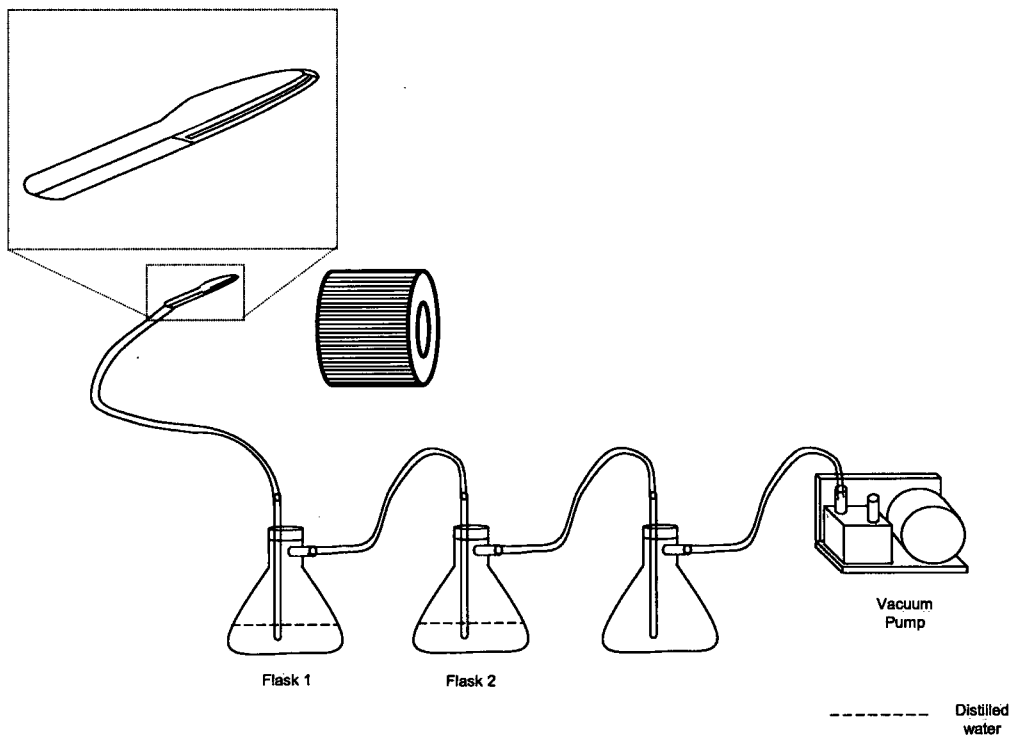
**Figure 2.7: Sampling road deposited sediment along the curb**



**Figure 2.8: Example of road deposited sediment sample collected over 20 m length of curb lane**



**Figure 2.9:** Filter pleats being vacuumed off into water flasks



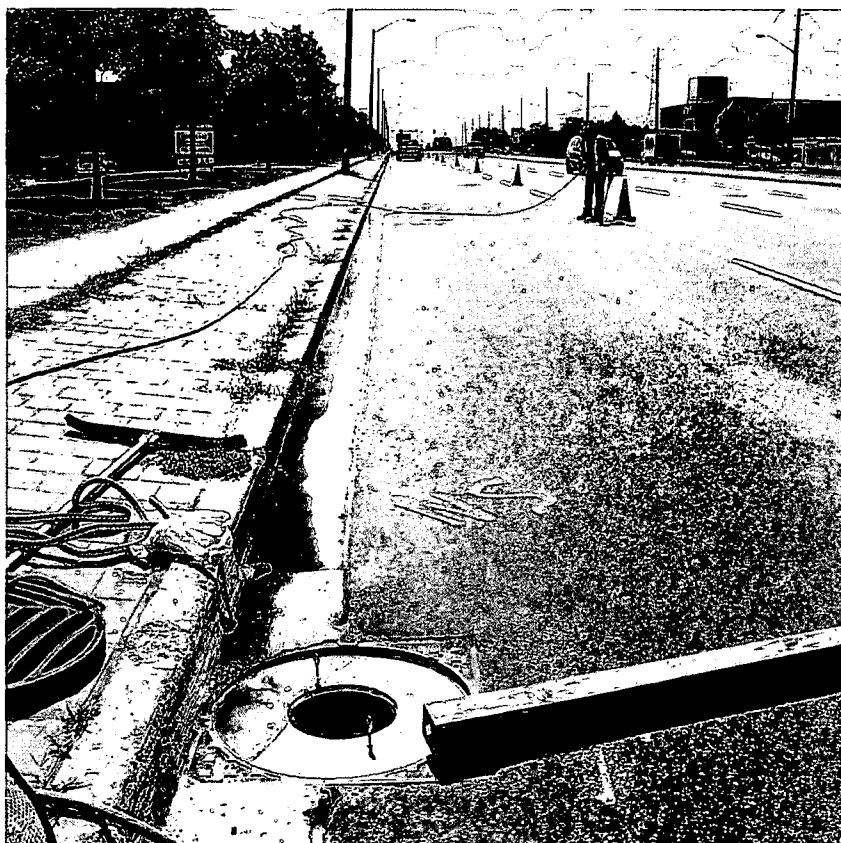
**Figure 2.10:** Filter vacuum system with specialized crevice tool and water flasks connected to vacuum

### 2.3.2 Wet sampling

The wet sampling was performed on an area similar to that used for the dry sampling (20 m x 4 m), but located immediately upstream of, and directly draining into, the catchbasin. The round catchbasin grate ( $D = 0.61$  m) was removed and replaced with a sealed catchbasin insert which collected all of the runoff from the site (see Figure 2.11). The catchbasin insert was 1.03 m deep and 0.25 m in diameter, for a total storage volume of approximately 50 L. Since the total volume of runoff generated was usually 70 L or more, some water had to be pumped into sample containers prior to completion of the washdown. The insert was sealed to the catchbasin with a flexible temporary caulking and a small recirculating pump was lowered to the bottom to provide mixing and facilitate sample collection. In addition, berms were placed downstream of the catchbasin to ensure that all of the runoff was retained within the test area. A hydrolab (DataSonde 4) was used to record temperature, pH, conductivity and dissolved oxygen in the insert as it filled up. A small pump and reservoir of tap water fed the washdown hose used to wash off the pavement and generate the runoff. Wash water was municipal tap water which had been dechlorinated by bubbling air through it and by further aging the water overnight. A garden hose fitted with a gentle rain-like spray head was moved in wide sweeping motions across the sampled area, moving from the highest elevation to the lowest and down along the curb. Washdown occurred over a consistent period of 16 minutes, so that application of water to the surface could be standardized. Measurements were collected to determine the total volume of water used and the time taken to wash down the area, but generally, 110 L of tapwater was applied within the 16 minutes and generated roughly 70 L of runoff. Note that this watering corresponded to a rainfall with an intensity of 5.16 mm/h, and a runoff coefficient of 0.64, indicating the initial hydrological abstraction (surface wetting and depression storage) of 0.5 mm. A photograph of the wet sample collection is shown in Figure 2.12.



**Figure 2.11:** Catchbasin insert installed in manhole and wand of wash down device showing simulated runoff generated



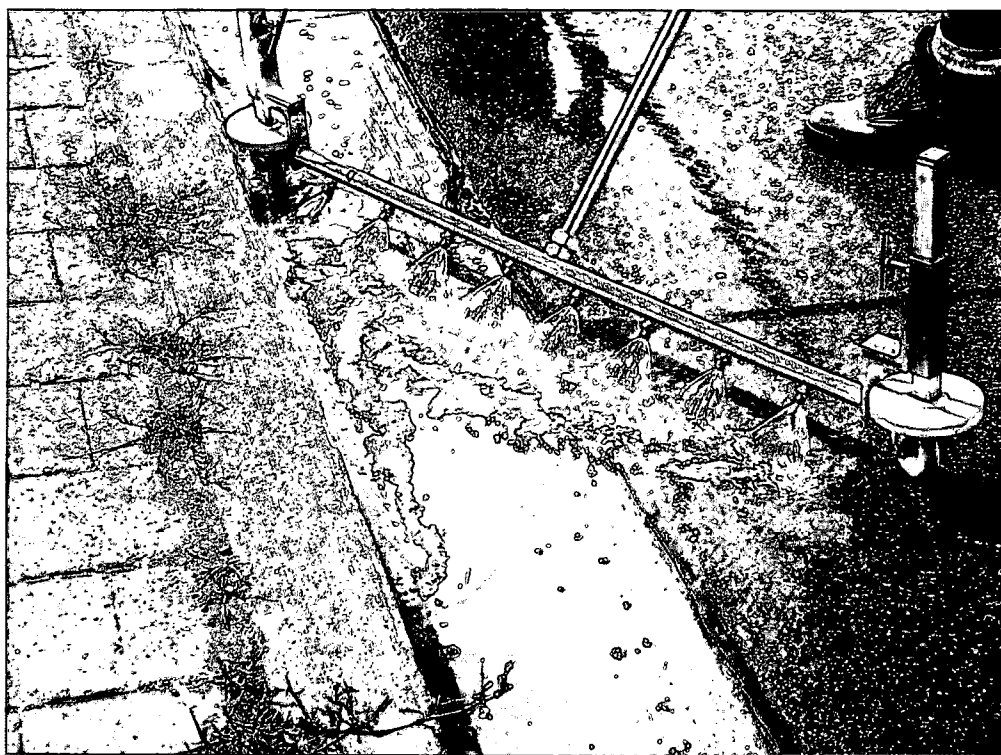
**Figure 2.12:** Wet sample collection – test catchment area

Since there were some minor technical problems identified during the 2004 field season, a few changes were made to the sampling techniques for 2005. These improvements included a larger catchbasin. The original catchbasin, as designed, could hold just 50 L and therefore would not contain the full amount of the runoff which was generated (estimated to be 60-70 L). This situation required that the catchbasin be partially emptied into the sample containers (20 L plastic pails for toxicity sampling, which were filled in parallel to avoid changes in concentration affecting toxicity results), to prevent overflow. The new, larger catchbasin (0.38 m diameter by 0.88 m – total volume ~100 L) ensured that the full volume of runoff generated, was captured.

In addition to the larger catchbasin, a new method of washing down the road was used in 2005. A stainless steel water broom with 8 nozzles was used to create the simulated runoff, which provided a more efficient wash down of the road surface. The water broom was powered by a stronger 1.49 kw (2 hp) stainless steel pump, which delivered approximately 110 L at 552 kPa (80 PSI) in 6.5 minutes (new intensity:  $i = 12.7$  mm/h). This new configuration is shown in Figure 2.13 and 2.14. Wash water was also acidified in 2005 runs. After dechlorination, a concentrated mixture of 60%  $\text{H}_2\text{SO}_4$  : 40%  $\text{HNO}_3$  (% by weight) was added to reduce the pH of the wash water to 6.0. In practice, however, this did not work as well as expected, and pH was often  $> 7.0$  by the following day.



**Figure 2.13: Wet sample collection – water broom**



**Figure 2.14: Water broom – detail of nozzles and curb washing technique**

## 2.4 Road Deposited Sediment Analyses

All samples were collected in the field using disposable brushes and clean stainless steel scoops and spatulas. Samples were stored in amber glass jars with Teflon lids. Upon returning to the lab, the road deposited sediment samples collected from the vacuum were weighed to determine their total mass and then split using a common "coning and quartering" method (Duncan and LaHaie, 1979). Road deposited sediment was divided into 4 fractions for further analysis:

1. One sub-sample was kept intact for a full particle size analysis using sieve and sedigraph methods,
2. A second sub-sample was sieved into three size fractions ( $> 2000 \mu\text{m}$ ,  $2000\text{--}64 \mu\text{m}$  and  $< 64 \mu\text{m}$ ) and processed further for chemistry analysis
3. A third sub-sample was used (in 2005 only) for solid phase toxicity work, and
4. The last sub-sample was stored for further analysis.

### 2.4.1 Particle size

All sub-samples were submitted to the National Water Research Institute (NWRI) Sedimentology Laboratory for particle size analyses. These analyses provide the composition of the sediment in terms of common size classes (gravel, sand, silt and clay). Particle size analyses were completed using a combination of the sieve method and the sedigraph method (the method used depending upon the size range of the sediment being analyzed). The sieving method takes a representative sub-sample from the core and places the sample in a set of varying gauge sieves (down to  $63 \mu\text{m}$ ). The sieves are placed on a shaker for 15-minutes and the fraction in each pan is weighed.

Sedigraph analyses are performed on a suspension of the representative sub-sample which passes through this smallest screen. The sample is dispersed with sodium metaphosphate and filtered through a  $63 \mu\text{m}$  screen. The sample which is retained on the screen is used to calculate gravel and sand fractions, and the sample which passes through undergoes further analysis by the sedigraph analyzer. Software is used to determine the appropriate distribution co-efficients and create particle size distribution charts (Duncan and LaHaie, 1979).

### 2.4.2 Sediment chemistry

The sub-samples for sediment chemistry were sieved through a set of clean stainless steel sieves, which divided the sample up into 3 fractions:  $> 2000 \mu\text{m}$ ,  $2000\text{--}64 \mu\text{m}$  and  $< 64 \mu\text{m}$ . The  $> 2000 \mu\text{m}$  fraction was weighed and discarded, and the  $2000\text{--}64 \mu\text{m}$  and  $< 64 \mu\text{m}$  fractions were then further divided using the coning and quartering technique described above. These sub-samples were submitted for total (acid extractable) metals, total phosphorus, total nitrogen, total organic carbon and PAHs.

#### 2.4.3 Sediment toxicity

Samples for sediment toxicity were processed according to the requirements for the Microtox™ solid phase test. A representative sub-sample (total mass 7.00 g) was measured out and placed in a test beaker. Samples were extracted using 35 mL of Microtox™ solid phase test diluent and mixed for 10 minutes. Aliquots were then incubated in a water bath at 15°C. Samples were filtered and a version of the acute Microtox™ test, adapted to solid phase samples, was performed (AZUR Environmental, 1998).

### 2.5 Simulated Runoff Analyses

Water samples were collected from the catchbasin insert using a submersible pump, which also served to produce well-mixed samples and helped to maintain solids in suspension by recycling the discharge back into the catchbasin insert. Three 20-L sub-samples were required for toxicity testing and they were filled in parallel to reduce the chance of potential changes in concentration which may occur without proper mixing. Specific information on chemistry and toxicity samples are given below. A hydrolab (DataSonde4) was used to record temperature, conductivity, pH, turbidity and dissolved oxygen in the catchbasin as it filled. Readings were extracted for the time period at the end of the wash down when the catchbasin was full and represented the average runoff values.

#### 2.5.1 Runoff chemistry

Samples for runoff chemistry were analyzed for a number of conventional parameters, including total suspended solids (TSS), total metals, dissolved metals, total phosphorus (TP), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), polycyclic aromatic hydrocarbons (PAHs) and particle size. The gravimetric analysis for TSS and the Malvern laser particle size analysis were performed on the liquid samples in the NWRI laboratory; all other analyses were performed by an outside contracted laboratory. Total and dissolved metals were analyzed by Inductively coupled plasma – mass spectroscopy (ICP/MS), total phosphorus and TKN were analyzed after digestion, using colorimetric methods, TOC was analyzed by the combustion non-dispersive infrared (NDIR) method and PAHs were analyzed by gas chromatography – mass spectroscopy (GCMS) (operated in Selective Ion Mode [SIM]). All samples collected in the field were preserved immediately and placed on ice. They were transferred to, and kept in, a refrigerated storage room at 4°C until analyzed.

#### 2.5.2 Runoff toxicity

Approximately 50 L of simulated runoff was collected for toxicity testing. The Ontario Ministry of Environment (MOE) performed both the Rainbow trout and *Daphnia magna* tests, while Microtox™ tests were performed at NWRI. Toxicity samples for the MOE were collected in 20 L food-grade polyethylene lined pails, and Microtox™ samples were



collected in 100 mL amber glass vials, with Teflon liners. Three pails were needed to provide samples for Rainbow trout LC50 96-hour static non-renewal tests (EPS 1/RM/13, Environment Canada, 2000) and *Daphnia magna* LC50 96-hour static non-renewal tests (EPS 1/RM/11, Environment Canada, 2000). The acute Microtox EC50 15-minute test was performed on the samples following the standard protocol (AZUR Environmental, 1998).

### 3 RESULTS

The following results summarize two years of field research at the test site on Markham Road in Toronto. For all the result charts, error bars represent the standard error about the mean (Origin, 2004; GraphPad/Prism, 2005). Standard error was selected in preference to 95% confidence limits, due to the small number of data points available. In the final version of this report, data analysis will be determined for the 95% confidence limits.

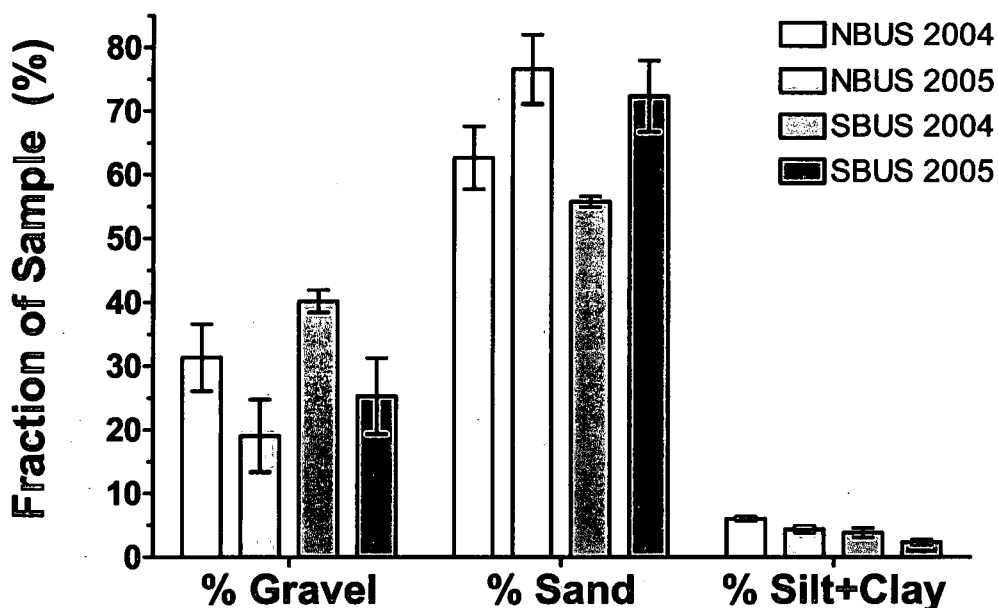
Results from both the control (unswept) sites and the areas swept by the three sweepers tested showed a wide variation, making effectiveness comparisons more difficult. This variation likely reflects the less-than-ideal “real-world” conditions which were exhibited during this test. Test conditions where atmospheric losses / gains could be controlled (e.g., an indoor test facility) and the sweeper cleanliness / peak operating effectiveness could be assured would probably result in more statistically significant differences.

#### **3.1 Background Characterization of Road Deposited Sediment of Unswept (Control) Surfaces**

##### *3.1.1 General characteristics*

Dry samples collected from unswept catchment areas provided data to characterize the source material available for the street sweepers to pick up. Figure 3.1 summarizes the fraction of gravel (defined as  $> 2000 \mu\text{m}$ ), sand (defined as  $64 - 2000 \mu\text{m}$ ) and silt + clay (defined as  $< 64 \mu\text{m}$ ) in the sediment collected at each site (northbound and southbound swept sites, over a period of two years).

The sand fractions dominated the composition of the samples, being  $> 50\%$  and as much as  $75\%$  on average. Less than  $7\%$  of the samples by weight, represented the silt + clay fraction and gravel accounted for  $20$  to  $40\%$  of the total sample mass. This is similar to findings from Breault et al. (2005), who reported an average of  $80\%$  sand (range  $71$  to  $87\%$ ),  $16\%$  gravel (range  $9$ - $25\%$ ) and an average of just  $4\%$  for silt and clay sized particles (range  $2$ - $5\%$ ).



**Figure 3.1:** Overall characterization of road deposited sediment by sediment class (northbound [NBUS] and southbound [SBUS] unswept sites)

Field observations during the first year of effectiveness testing suggested that there might be differences in the amount and type of material in the southbound lanes compared to the northbound ones. It was for this reason that background characterization (unswept) samples from northbound (NBUS) and southbound (SBUS) lanes were not combined for these analyses. As can be seen in Figure 3.2, there was significantly less gravel in the northbound and southbound lanes in 2004 when compared to 2005. There was also less gravel in the northbound lane in 2005 when compared to the northbound lane in 2004. Sand was a major component of all samples collected from these sites, comprising 55% or more of the total sediment load (Figure 3.3). Northbound lane samples in 2004 were higher in sand than the southbound lane samples in 2004 (this was reflected by the higher proportion of gravel in southbound lanes), however there was no significant difference between northbound and southbound lane samples in 2005. In both years, the fraction of sand in the sample increased from 2004 to 2005. The silt + clay fraction contributed just 2 to 6% of the total mass of the sample (Figure 3.4). Southbound lanes in both years showed lower fractions of silt + clay than the northbound lanes and there was a significant reduction in the fraction of silt + clay between 2004 and 2005 for both northbound and southbound.

Based on field observations, a number of active construction sites were located north of the research area and construction debris could have been carried into the southbound lanes from sites further north. The dominance of sand (up to 75%) in 2005 was likely also attributable to the construction activity.

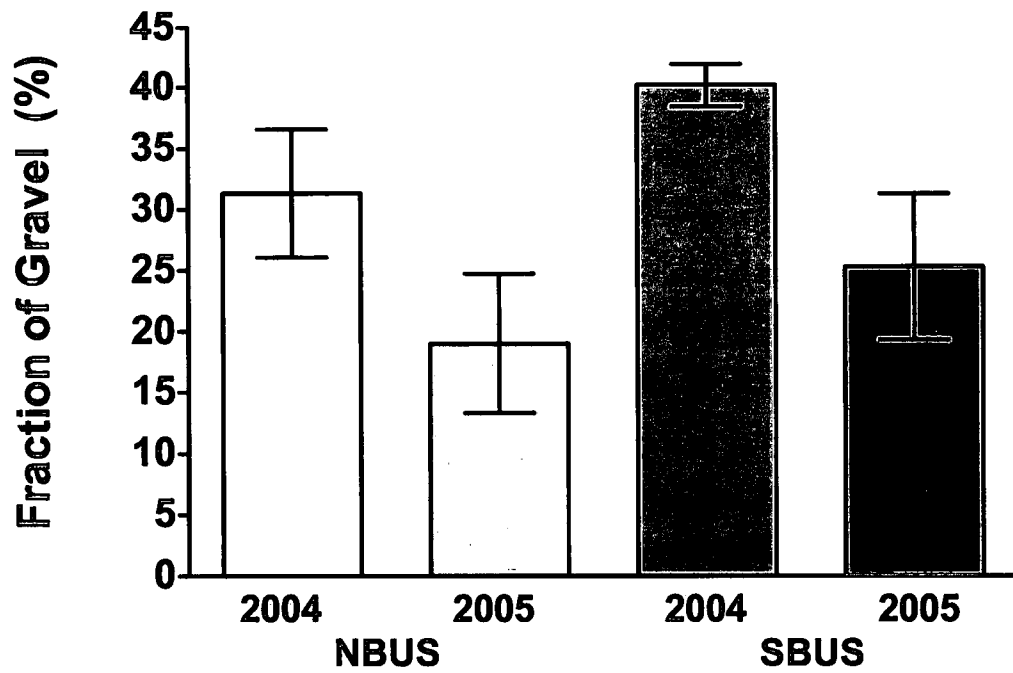


Figure 3.2: Fraction of gravel in road deposited sediment material (northbound and southbound unswept sites)

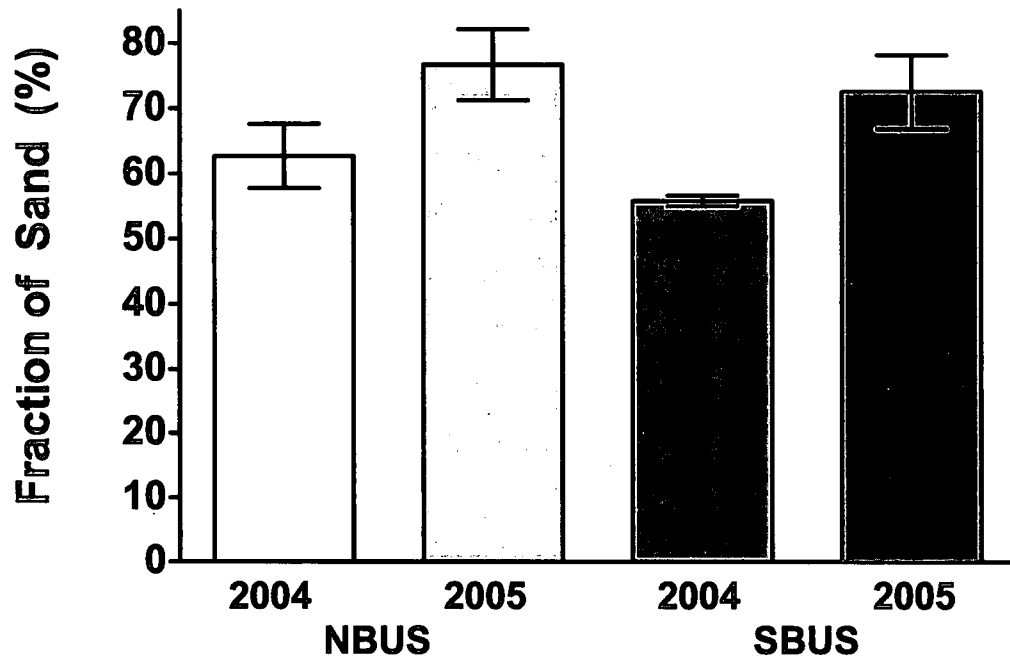
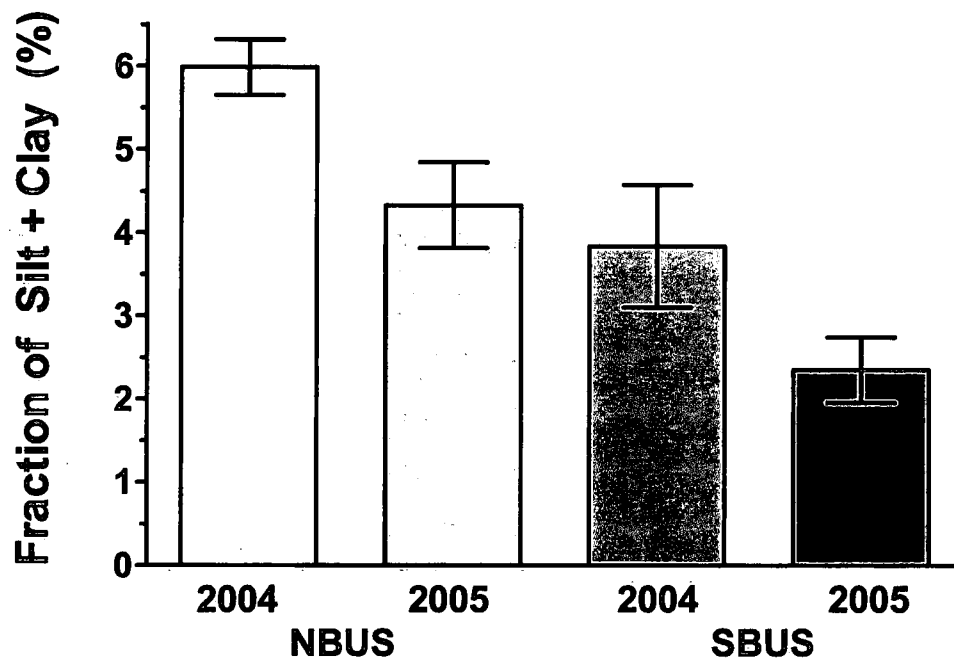


Figure 3.3: Fraction of sand in road deposited sediment material (northbound and southbound unswept sites)



**Figure 3.4:** Fraction of silt + clay in road deposited sediment material (northbound and southbound unswept sites)

### 3.1.2 Mean particle size

Figure 3.5 compares the mean particle size for northbound and southbound lanes for both 2004 and 2005. In 2004, there was a significantly larger mean particle size southbound (1245  $\mu\text{m}$ ) compared to northbound (940  $\mu\text{m}$ ), but this difference was not evident in 2005. When the data from both years was pooled together, however, no significant differences were observed for mean particle size between either location (see Figure 3.6).

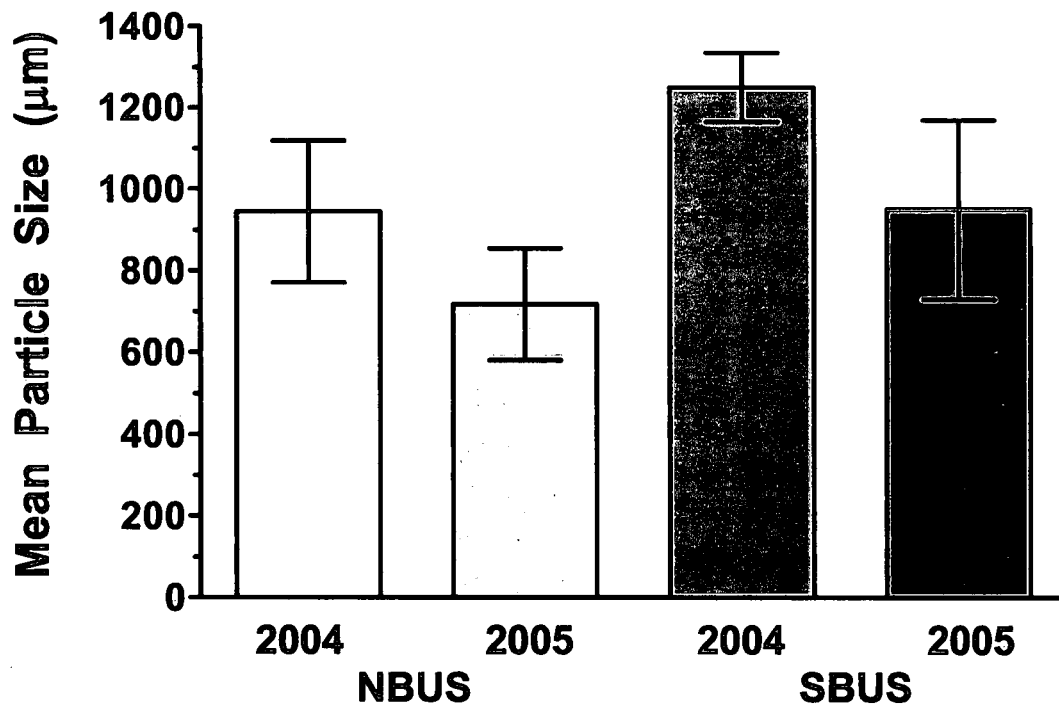


Figure 3.5: Mean particle size (northbound and southbound unswept sites, 2004 and 2005)

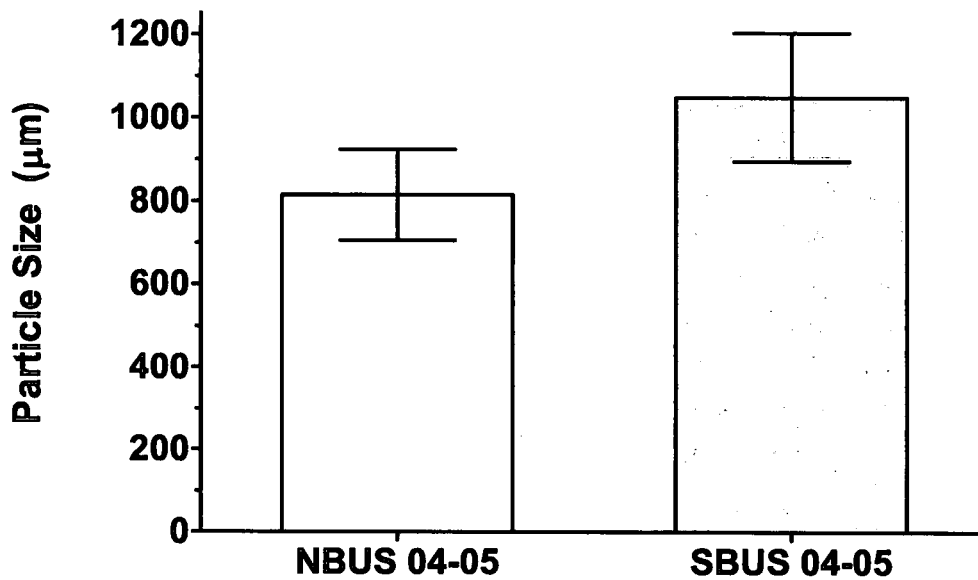


Figure 3.6: Mean particle size (combined northbound unswept sites 2004-05 and combined southbound unswept sites 2004-05)

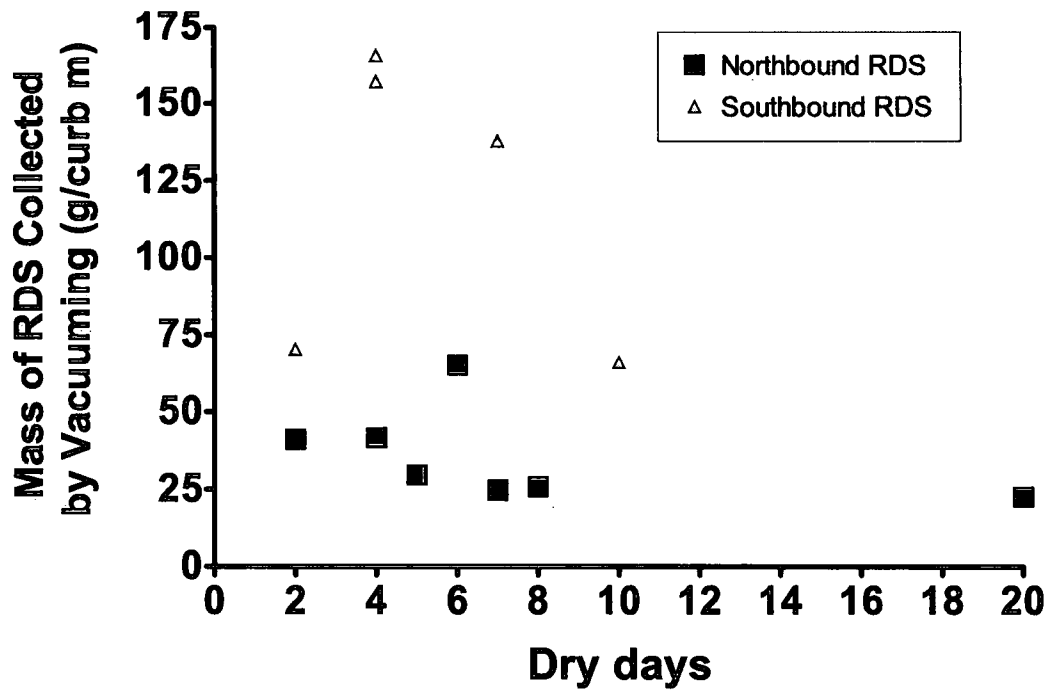
### 3.1.3 Sediment accumulation rates

Due to relatively frequent rainfall during experimental periods, only limited data were available for determining sediment accumulation rates; just two intervals between sampling events were without any rainfall. Between the September 14 and the September 23, 2004 sampling events (a period of 8 dry days), a total of 516.5 g had built up on the northbound lanes (an area of 80 m<sup>2</sup>, with a curb length of 20 m). Assuming that the buildup occurred uniformly over time, an accumulation rate could be calculated as:

$$\text{Accumulation Rate} = \frac{\text{total mass/curb length}}{\text{time}} \quad (3.1)$$

Using the above numbers in equation 3.1 yields a value of 3.2 g/curb m/d (total mass = 516.5, curb length = 20 m and time = 8 days). If it was assumed that the accumulations actually leveled off after 3 days, as commonly indicated in the literature (Sartor and Boyd, 1972; Pitt et al., 2004; Breault et al., 2005), the estimated accumulation rate would increase to 8.6 g/curb m/d (all other parameters being equal, time reduces to 3 days from 8 days). Between the September 23 and the October 7, 2004 sampling events, (a period of 10 dry days), a total of 1324 g had built up on the southbound lanes (an area of 80 m<sup>2</sup>, with a curb length of 20 m). Again, using equation 3.1, this resulted in an accumulation rate of 6.6 g/curb m/d. If the accumulation rate was assumed to level off after just 3 days (thereby reducing time from 10 days to 3 days), this would increase the accumulation rate estimate to 22 g/curb m/d. The literature suggests that 9 g /curb m/d could be considered an average accumulation rate for residential / commercial streets in good condition, and the expected range fell between 1 and 40 g/curb m/d, with accumulation rates up to 50% higher for rough or textured streets (Pitt et al., 2004). Although based on limited data, the numbers generated from this field site seem to agree well with those indicated in the literature and suggest that the site could be considered to have average to above average accumulation rates.

Figure 3.7 shows the comparison of accumulation of road deposited sediment (RDS) and the number of antecedent dry days (where rainfall was less than 7 mm). The accumulated sediment was sampled by thorough vacuuming with an industrial vacuum and was the best available technology for sampling the material, but was not guaranteed to be 100% efficient. Experiments in the laboratory showed that the vacuum was capable of picking up fine material (3-10 µm) at 97% efficiency from concrete in good condition (Fralick, 2005). The black squares indicate the northbound lane accumulations and the triangles indicate the southbound lane accumulations. Although only seven data points are available for these accumulation rates on the northbound lanes, the general trend fits that described by Sartor and Boyd (1972). Accumulation rates for the northbound lanes appear to level off around 50 g/curb m. Road deposited sediment for the southbound lanes was likely heavily influenced by the local construction (further north of the test area) and did not appear to follow a buildup trend which could be easily identified.

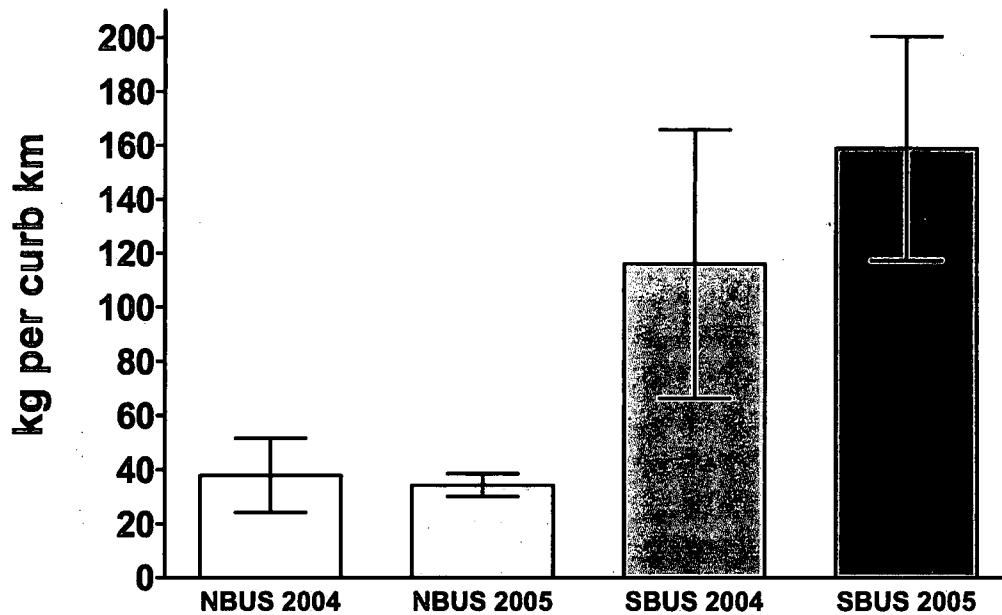


**Figure 3.7:** Mass of road deposited sediment (RDS) collected by vacuuming (northbound and southbound unswept sites 2004 and 2005)

#### 3.1.4 Sediment loads on unswept areas

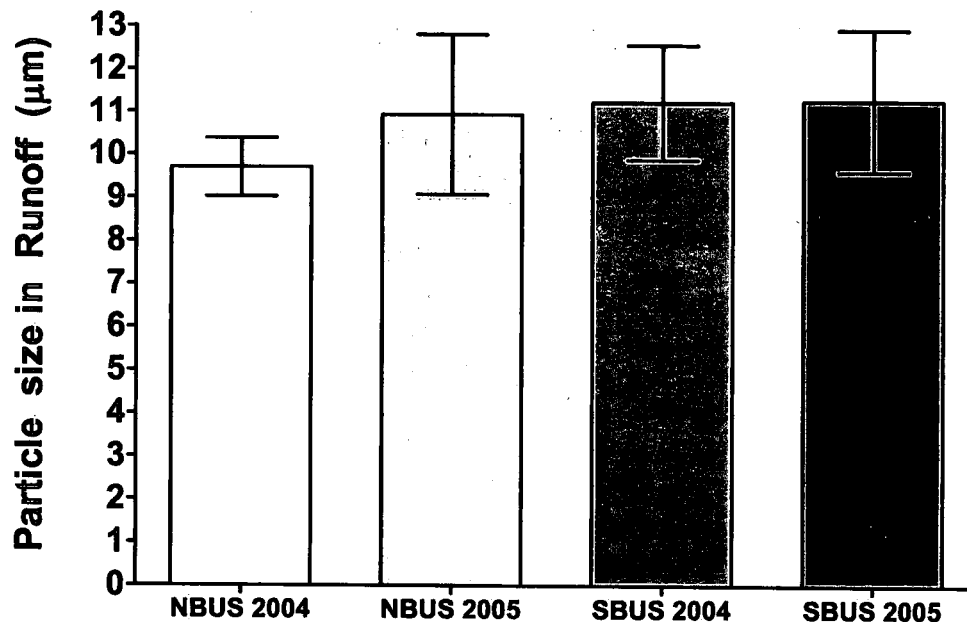
Although sediment particle size distributions were not different between northbound and southbound lanes, total sediment loads were significantly different. There was no difference between years (2004 and 2005), but the mean sediment load was 35.6 kg/curb km for northbound lanes and 145 kg/curb km in the southbound lanes (see Figure 3.8). This was approximately 4 times higher and likely a result of transport of construction debris from sites located just to the north of the test area.





**Figure 3.8:** Mean sediment load (northbound and southbound unswept sites 2004 and 2005)

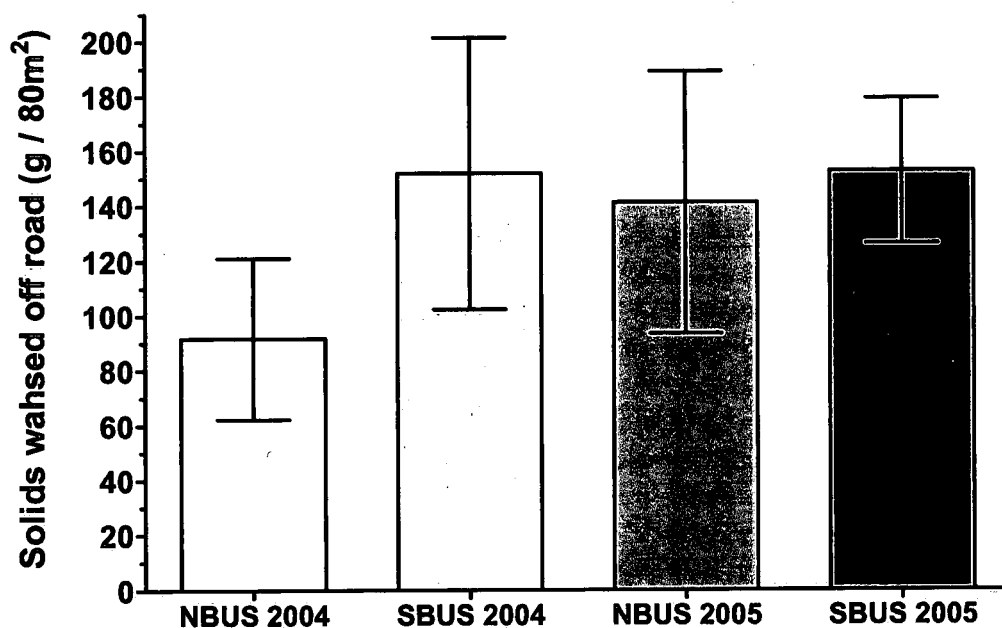
Although two different methods were used to wash-off road deposited sediment during experiments to generate simulated runoff, there was no significant change in the total mass of solids conveyed to the catchbasin in simulated runoff tests from unswept areas (Figure 3.9). The mean particle size was  $10.7 \mu\text{m}$  for all years and sites. This suggested that the method of washoff (gentle rain from garden hose vs. fan-jet light-pressure water broom) was not affecting the particle size of solids washed off the catchment, despite the perceived improvement in efficiency by the field personnel. Also, the results suggest that both washing methods provided adequate hydraulic transport for fine silt and clay particles, but not for sand or gravel, since the maximum recorded particle size in the simulated runoff was usually less than  $100 \mu\text{m}$ .



**Figure 3.9:** Particle size in runoff samples (northbound and southbound sites - 2004 and 2005)

### 3.1.5 *Transport of sediment under simulated runoff conditions*

Simulated runoff generated suspended solids were measured in samples collected from the sealed catchbasin. Since the volume of water used to wash down the catchment area was not the same in each case, total solids washed off the road (calculated as the volume of water used  $\times$  TSS of runoff = total solids washed off road/ $80 \text{ m}^2$ ) was used to standardize the results. Of particular interest was the sample collected from SBUS on 27 October, 2005. On this date, suspended solids were excessively high (3 times higher than normal). For this reason, the chart shown below (see Figure 3.10) does not include this data point. It can be noted that the amount of solids washed off each test catchment (NBUS and SBUS) were relatively constant, both from year-to-year and from northbound to southbound. This would suggest that the new washoff method (which changed between 2004 and 2005) did not convey significantly more solids to the catchbasin (despite its perceived increased efficiency). The overall mean for all unswept sites was  $129 \text{ g} / 80 \text{ m}^2$  (when excluding the data point from SBUS 27 October, 2005) and represented 10-25% of accumulations measured by vacuuming. Low solids collection by washing suggests that the water broom may be less effective in dislodging street surface particles than the combined action of the brush/industrial vacuum (see the Methods section) and/or the hydraulic transport generated by the water broom was not sufficient to transport the coarser dislodged particles to the inlet sampler.



**Figure 3.10:** Mean weight of solids washed off the road from unswept sites (northbound and southbound sites 2004 and 2005)

### 3.1.6 Chemical evaluation of road deposited sediment

Early comparisons suggested that there was a difference in the background (unswept) conditions between northbound and southbound lanes but since different sweepers were used to sweep different sides of the street in 2004, the pooling of northbound and southbound datasets could not be done. In 2005, the same sweeper was used to sweep both sides of the street but the data was analyzed separately (northbound and southbound). Only after data analysis had shown that there was no difference between northbound and southbound data, they were combined into a single data set.

The chemical characteristics of the road deposited sediment from unswept test sites were also evaluated to determine background conditions for dry road deposited sediment. In all cases, the northbound and southbound sites were analyzed separately to determine if there was any statistical difference between sources. Where there was no difference between northbound and southbound sites, the results were combined and a single average presented. A wide range of chemical components were evaluated (nutrients – Table 3.1, some key metals – Table 3.2 and three PAHs – Table 3.3), and encompassed two different particle size ranges ( $<64\ \mu\text{m}$  and  $64 - 2000\ \mu\text{m}$ ). The results show that generally, northbound sites had higher concentrations of contaminants than the southbound sites and, as would be expected, the  $<64\ \mu\text{m}$  size fraction contained more contaminants per unit mass than the  $64 - 2000\ \mu\text{m}$  size range. Some notable exceptions included Cu on the SBUS site in 2004 and Pb on the northbound site in 2004. Only the means are presented in the tables below. A complete summary of all road deposited

sediment data for nutrients, metals and PAHs is included in Appendix B of this data report.

**Table 3.1:** Unswept sites chemical composition of road deposited sediment – Mean nutrient concentrations

	Year	Location	< 64 µm (mg/kg)	64 – 2000 µm (mg/kg)
TOC	2004	NBUS	37,000	14,000
		SBUS	21,500	9,000
	2005	NBUS	45,000	21,750
		SBUS	28,000	11,750
TKN	2004	NBUS	1,200	353
		SBUS	805	250
	2005	NBUS	844	289
		SBUS	785	152
TP	2004	NBUS	823	510
		SBUS	720	465
	2005	NBUS	820	493
		SBUS	870	465

**Table 3.2:** Unswept sites composition of road deposited sediment – Mean metal concentrations

	ISQG <sup>1</sup> (mg/kg)	PEL <sup>1</sup> (mg/kg)	LEL <sup>2</sup> (mg/kg)	SEL <sup>2</sup> (mg/kg)	Year	Location	< 64 µm (mg/kg)	64 – 2000 µm (mg/kg)	Stone& Marsalek SOO	Skyway Sediment
Cr	37.3	90	26	110	2004	NBUS	69	61	92.4	---
						SBUS	46	53		
					2005	NB/SBUS	160	100		
Cu	35.7	197	16	110	2004	NBUS	207	135	87.3	314
						SBUS	103	196		
					2005	NB/SBUS	206	120		
Pb	35.0	91.3	31	250	2004	NBUS	64	208	90.5	402
						SBUS	39	45		
					2005	NB/SBUS	74	39		
Zn	124	271	120	820	2004	NBUS	507	230	227	997
						SBUS	265	300		
					2005	NB/SBUS	544	243		

<sup>1</sup> Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) – Canadian sediment quality guidelines (CCME, 2002)

<sup>2</sup> Lowest Effect Limits (LEL) and Severe Effect Limits (SEL) - Ontario sediment quality guidelines (MOE, 1992)

Comparisons of road deposited sediment data from this study and those from a Canadian industrial city (Sault Ste. Marie) (Stone and Marsalek, 1996) shows a good agreement, but the road deposited sediment contained much lower metal burden than sediment from the Skyway bridge (Marsalek et al., 1997). All sites were contaminated above the federal Interim Sediment Quality Guidelines (ISQG) and provincial lowest effect limits (LEL)

for the metals selected, and some were also contaminated to the point where they may require special considerations for disposal, (exceeding either the federal PEL and / or the provincial SEL).

**Table 3.3: Unswept sites chemical composition of road deposited sediment – Mean PAH concentrations**

	ISQG <sup>1</sup>	PEL <sup>1</sup>	Year	Location	< 64 µm	64 – 2000 µm	Skyway Bridge <sup>2</sup>
	(mg/kg)	(mg/kg)			(mg/kg)	(mg/kg)	(mg/kg)
Phenanthrene	0.04	0.52	2004	NBUS	1.05	0.39	5.032
				SBUS	0.57	0.37	
			2005	NB/SBUS	1.00	0.50	
Fluoranthene	0.11	2.36	2004	NBUS	1.73	0.65	3.839
				SBUS	1.00	0.46	
			2005	NB/SBUS	2.30	0.80	
Pyrene	0.05	0.88	2004	NBUS	1.33	0.52	2.889
				SBUS	0.75	0.46	
			2005	NB/SBUS	1.90	0.70	

<sup>1</sup> Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) (CCME, 2002)

<sup>2</sup> Concentrations in runoff sediment

PAH Concentrations in street sediment were typically 5-12 times lower than those in runoff sediment from Skyway Bridge with high traffic volume (on average 92,000 vehicles /24 h). All road deposited sediment was contaminated above the ISQG, but only a few sites exceeded the PEL for the selected PAHs and may require special consideration for disposal.

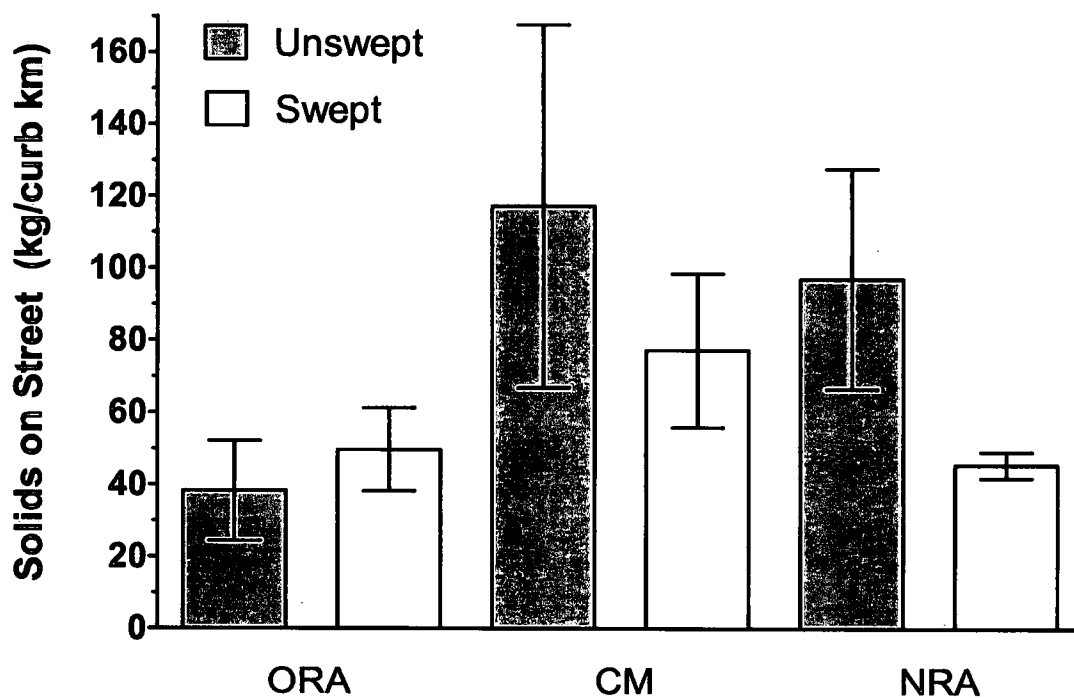
## 3.2 Effects of Street Sweepers on Road Deposited Sediment

### 3.2.1 Effects of street sweepers on particle size and total mass

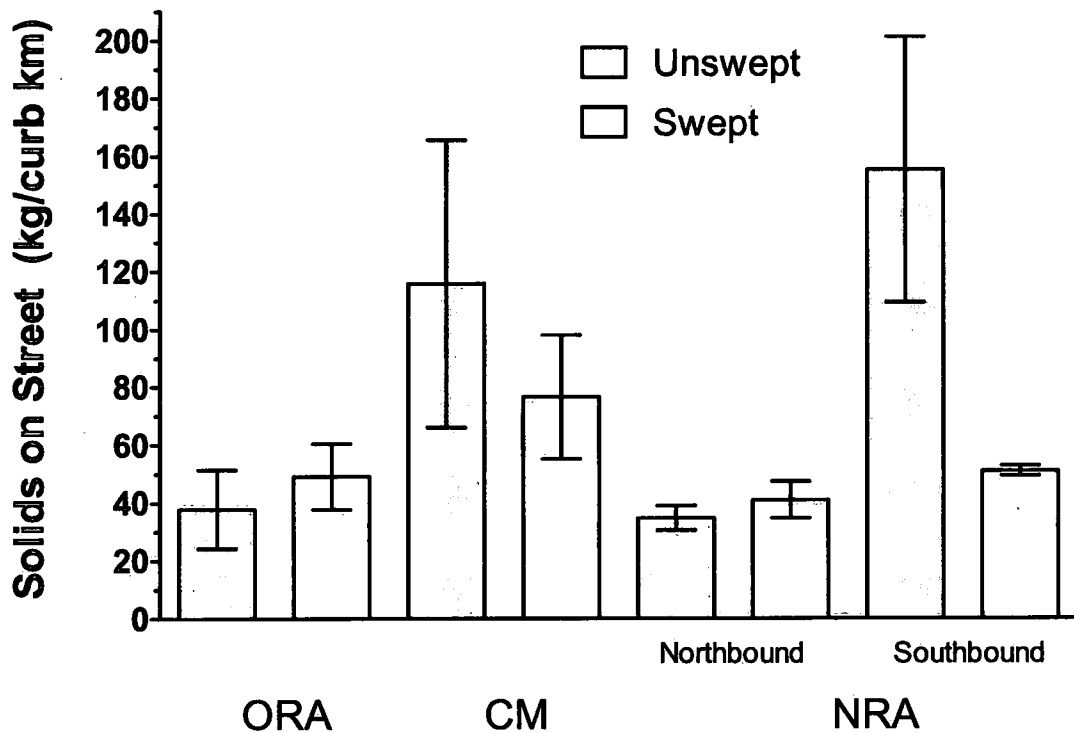
The total mass of solids collected over the dry test area (20 m x 4 m = 80 m<sup>2</sup>), was used to estimate the mass per curb kilometre which was present on the road. In this case, it was calculated as mass collected over entire test area divided by the number of square metres. In the figures which follow, the results fall under the old regenerative air (ORA), conventional mechanical (CM) and the new regenerative air (NRA).

The effectiveness of the sweepers at removing dry solids from the street was evaluated by comparing the mass of solids collected over the dry test area in both swept and unswept locations. Unswept data were collected for reference; masses (M) of solids from swept areas indicated how much of the total load the sweeper left behind. Thus, the larger the difference (M<sub>unswept</sub> – M<sub>swept</sub>), the higher the sweeper efficiency. Figure 3.11 shows that the only sweeper effective in removing a statistically significant mass of solids from the road surface was the new-technology regenerative air sweeper (M<sub>unswept</sub> – M<sub>swept</sub> = 48 kg/curb km). Note that the conventional mechanical sweeper exhibited similar effectiveness (40 kg/curb km), but the spread in the data showed that this value was not statistically significant. The old regenerative air sweeper, which was tested on the

northbound lanes only, showed no improvement. Figure 3.12 reveals that in fact, the sweeper was really only effective on the southbound lanes; the northbound lanes showed no removal of solids. In the southbound lanes, the average decrease in solids load after sweeping was about 100 kg/curb km. Figure 3.12 suggests that the new regenerative air sweeper appeared to remove solids down to a certain “background (residual) level” (approximately 40-60 kg/curb km), beyond which further removal appeared unlikely. Since the mass of solids on the northbound side of the street may have already been at that residual level, no further reduction of solids was noted. The observed increase in solids could have been a result of abrasion of road surfaces or solids imported from other locations being re-deposited as the sweeper passed by with dirty brooms. These data indicate that sweepers are particularly effective on streets with high solids accumulations; thus, to increase the effectiveness of street sweeping operations in pollutant source control, sweepers should be deployed preferentially and more frequently on such streets.

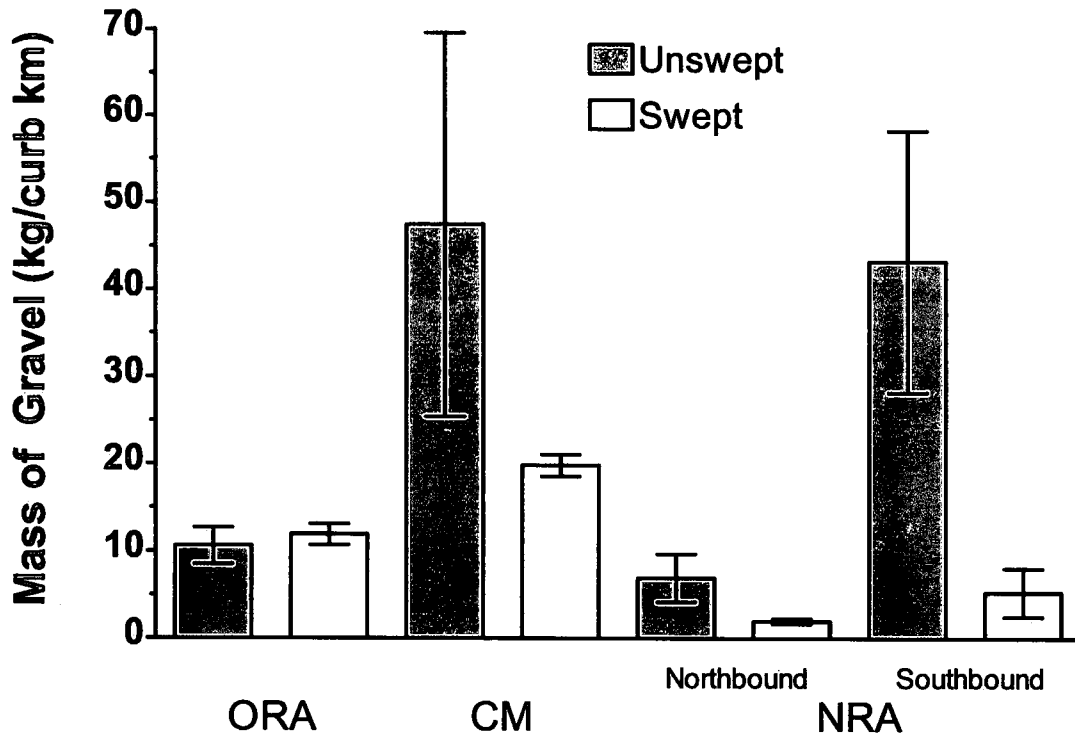


**Figure 3.11:** Sweeper effectiveness - Total mass of solids collected at swept and unswept sites – northbound and southbound lanes combined (2004 and 2005)



**Figure 3.12:** Sweeper effectiveness - Total mass of solids collected at swept and unswept sites – northbound and southbound lanes separate (2004 and 2005)

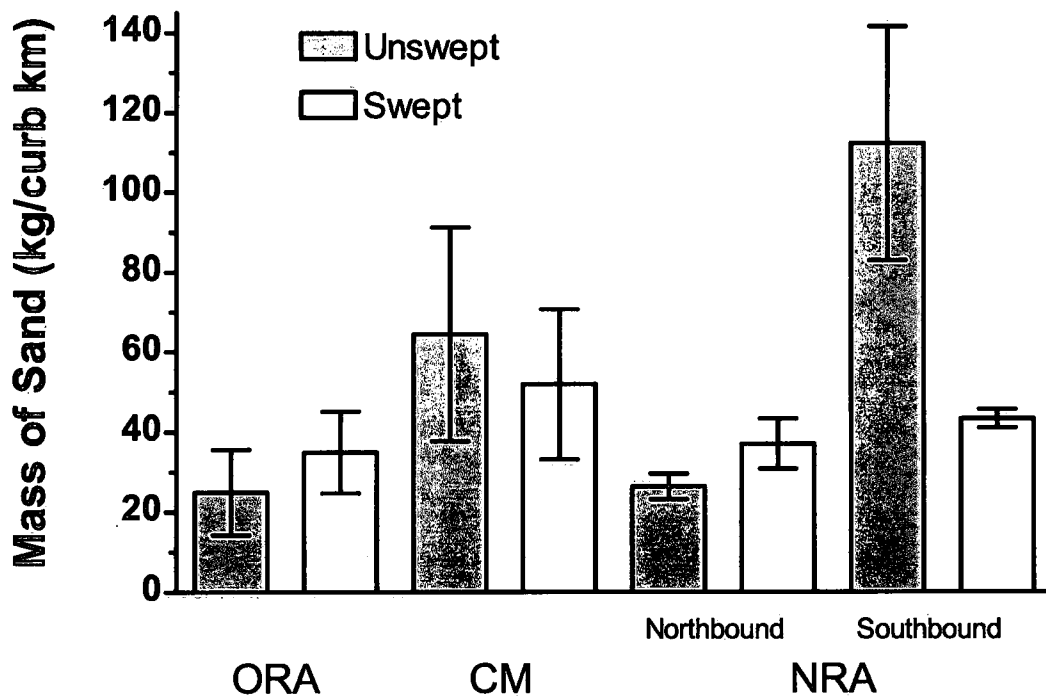
Although the overall removal of solids from the road was an important factor in determining how well a street sweeper performed, the efficiency of removal of a particular size fraction was also of interest. Figure 3.13 shows the mass of gravel (calculated as the fraction of gravel x total mass collected from the street surface) removed from the street surfaces during testing for all three sweepers. It can be seen that although the southbound lane control site (conventional mechanical unswept and new regenerative air SBUS) was usually much higher in the total mass of gravel when compared to the northbound control site, both the conventional mechanical and new regenerative air sweepers provided consistent reductions (58% and 88% respectively) in this component. The new regenerative air sweeper was also capable of removing the gravel from the northbound lanes (73% efficiency), but the old regenerative air sweeper was unable to remove gravel. This would suggest that the old regenerative sweeper did not produce sufficient lift on gravel particles to collect them from the street surface.



**Figure 3.13:** Sweeper effectiveness - Total mass of gravel at swept and unswept sites – northbound and southbound lanes separate (2004 and 2005)

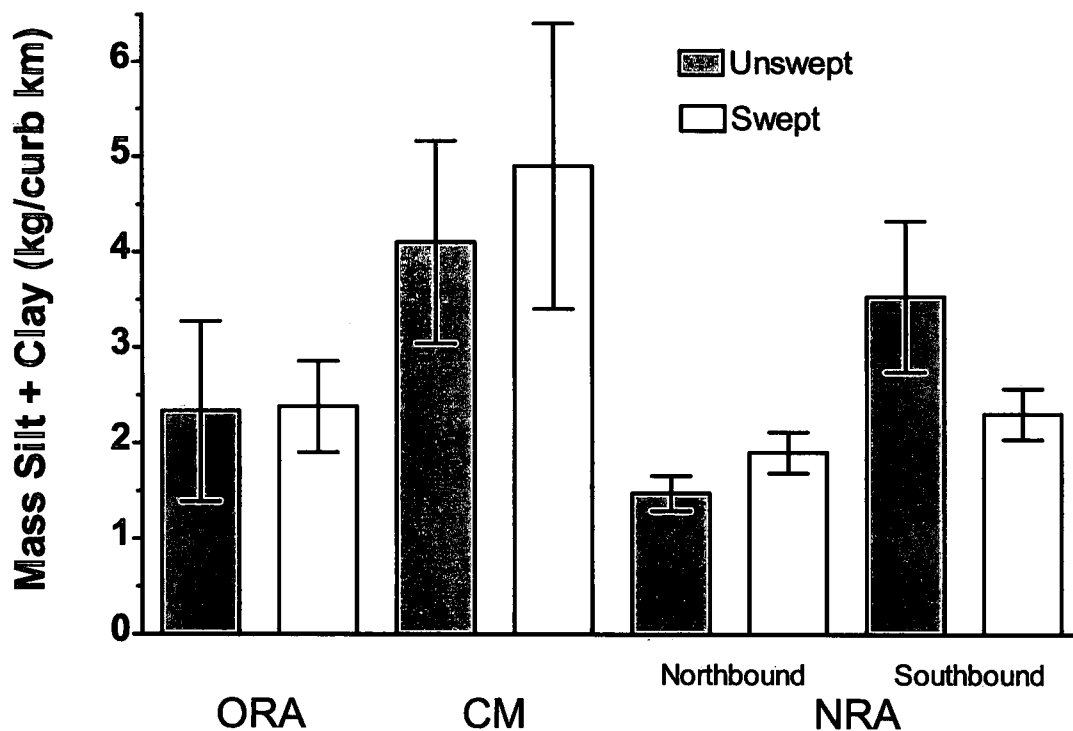
Since sand is a major component of all road deposited sediment (Pitt et al., 2004), the efficiency of a sweeper at removing sand becomes a key issue. As can be seen from Figure 3.14, only the new regenerative air sweeper was able to significantly reduce the sand content in road deposited sediment, and this only occurred on the southbound lanes (62% removal efficiency). Since once again, on the northbound lanes, there appeared to be no removal, but southbound lanes showed some improvement, it strengthens the argument that the sweepers may only be able to pick up material from the street down to some “background” level.





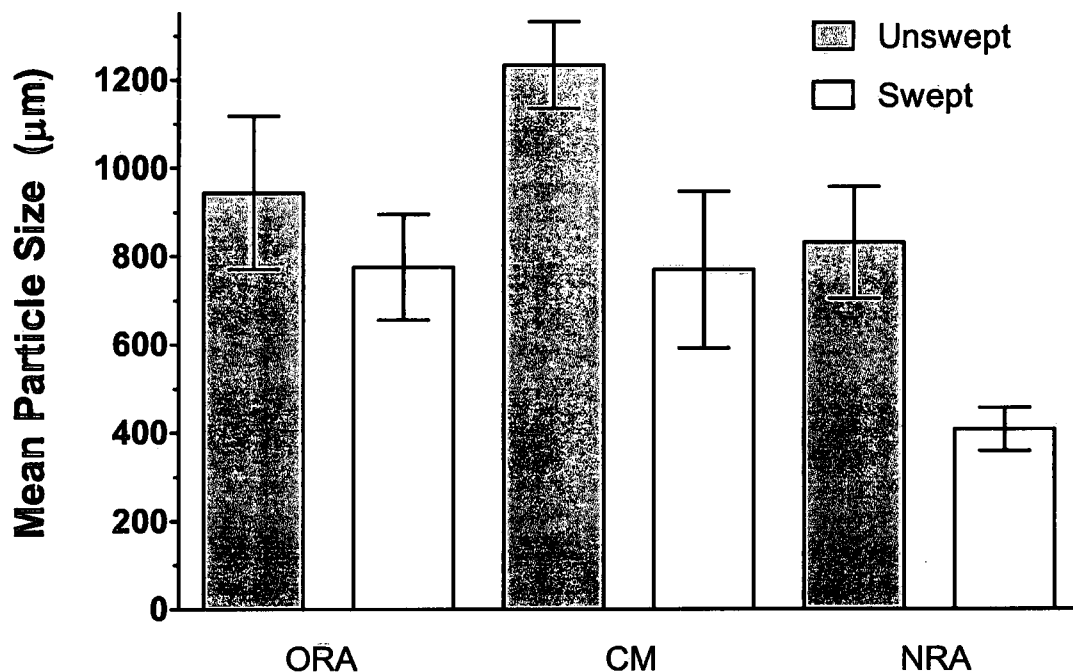
**Figure 3.14:** Sweeper effectiveness - Total mass of sand at swept and unswept sites – northbound and southbound lanes separate (2004 and 2005)

With advances in street sweeping technology, sweepers are becoming more efficient at picking up fine particles (such as the silt & clay fraction). Under these field conditions, once again (Figure 3.15) the new regenerative air sweeper was the best at picking up the fine material from the southbound lanes (35% removal efficiency), but this same reduction was not evident in tests on the northbound lanes, where there was no significant change. It may again be evidence which demonstrates that a limit may exist, as to the amount of material which can be extracted from the road surface by any of the sweepers under real-world conditions, where the residual material loads were determined by meticulous vacuuming with a powerful industrial vacuum cleaner.



**Figure 3.15: Sweeper effectiveness - Total mass of silt & clay at swept and unswept sites – northbound and southbound lanes separate (2004 and 2005)**

It was expected that all the sweepers tested would easily remove large material (including gravel and sand), but would likely have more trouble removing the fine silt & clay material. When comparing the mean particle size (calculated by moments), all the three sweepers reduced the mean particle size in swept plots, but such reductions were statistically significant only in the case of the conventional mechanical and the new regenerative air sweepers (Figure 3.16). There was no significant difference between the particle sizes in the northbound and southbound lanes, when analyzed separately, so they were combined in this chart. It is important to note that even though the reduction in mean particle size was over 50% for this sweeper, it still left solids behind with a mean particle size of over 400  $\mu\text{m}$ .



**Figure 3.16:** Sweeper effectiveness – Changes in mean particle size

### 3.2.2 Effects of street sweepers on sediment chemistry

The effect of sweepers was also evaluated based on their ability to remove road deposited sediment having high concentrations of contaminants and nutrients. The removal of these particles is critical to the effectiveness of the sweeper for the purpose of source control. Table 3.4 shows the mean concentrations of sediment left behind by each sweeper for the two size fractions investigated. Only means are presented here and it is likely that some of the high concentrations which appeared in the October 7, 2004 samples would influence these means. There was relatively little change between swept and unswept sites. Table 3.4 indicates that nutrients were preferentially associated with finer street particles, which is in agreement with the findings of Vaize and Chiew (2004). Table 3.5 summarizes the metals concentrations before and after sweeping. The changes between swept and unswept were relatively minor for the selected metals, although the old regenerative air and conventional mechanical seemed to result in more increases, compared to the similar or decreased concentrations imparted by the new regenerative air sweeper. Table 3.6 shows similar results for the selected PAHs. The PAH results from the October 7, 2004 sampling event (conventional mechanical sweeper) showed much higher PAHs in the 64-2000 µm size fraction than in the <64 µm fraction and biased the mean results presented in Table 3.6. Generally, the PAHs were observed to have higher concentrations in the <64 µm fraction. A complete summary of sediment chemistry results (nutrients, metals and PAHs) are included in Appendix B of this data report.

**Table 3.4: Effect of sweepers on sediment sample chemistry – Mean nutrient concentrations**

Sweeper	Parameter	Unswept		Swept	
		< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)	< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)
Old	TOC	37,000	14,000	35,000	12,000
Regenerative	TKN	1,200	353	1,050	317
Air	TP	823	510	780	553
Conventional	TOC	21,500	9,000	26,000	13,500
Mechanical	TKN	805	250	995	450
	TP	720	465	665	475
New	TOC	36,800	16,800	38,100	15,900
Regenerative	TKN	825	226	881	393
Air	TP	751	426	731	449

**Table 3.5: Effect of sweepers on sediment sample chemistry – Mean metal concentrations**

Sweeper	Parameter	Unswept		Swept	
		< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)	< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)
Old	Cr	69.3	61.0	72.3	64.7
Regenerative	Cu	207	135	217	167
Air	Pb	64.3	208	68	44
	Zn	507	230	467	247
Conventional	Cr	46.0	52.5	59.0	49.5
Mechanical	Cu	103	196	108	105
	Pb	39.0	44.5	46.0	23.0
	Zn	265	300	295	185
New	Cr	160	100	160	93
Regenerative	Cu	206	120	178	161
Air	Pb	74.1	38.6	70.8	60.8
	Zn	544	243	509	230

**Table 3.6: Effect of sweepers on sediment sample chemistry – Mean PAH concentrations**

Sweeper	Parameter	Unswept		Swept	
		< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)	< 64 $\mu\text{m}$ (mg/kg)	64-2000 $\mu\text{m}$ (mg/kg)
Old	Phenanthrene	1.05	0.39	0.93	0.33
Regenerative	Fluoranthene	1.73	0.65	1.43	0.52
Air	Pyrene	1.33	0.52	1.37	0.45
Conventional	Phenanthrene	0.57	0.37	1.16	2.52
Mechanical	Fluoranthene	1.00	0.46	2.65	3.98
	Pyrene	0.75	0.46	1.48	2.37
New	Phenanthrene	1.00	0.50	1.00	0.50
Regenerative	Fluoranthene	2.30	0.80	2.10	1.00
Air	Pyrene	1.90	0.70	1.80	0.80

### 3.3 Effects of Street Sweepers on Simulated Runoff

#### 3.3.1 Effects of street sweepers on Runoff chemistry

One of the main goals of using street sweeping as a method of source control was to reduce the solids loading to the receiving waters. The complete summary of water chemistry results for the simulated runoff is presented in Appendix C. A comparison of Total Suspended Solids (TSS) in the catchbasin showed that no sweeper was able to reduce the concentration of TSS in the runoff by sweeping (Figure 3.17). Even when the northbound and southbound sides were analyzed separately and certain outlier values were excluded (dates where high TSS values corresponded to field observations of “dirty sweepers”), there was no difference between the swept and unswept sites. Figure 3.17 shows values with all data points included. The two different washoff methods used in 2004 and 2005 (rain shower hose nozzle and light-pressure water broom) produced very similar results. Both years showed the same size range of particles were being washed off and into the catchbasin insert (approximately 90% of solids in runoff were  $< 50 \mu\text{m}$ ), with mean particle sizes of  $10 \mu\text{m}$  (2004) and  $11.7 \mu\text{m}$  (2005). This would suggest that only the silt and clay material ( $< 64 \mu\text{m}$ ) would be washed off under normal conditions.

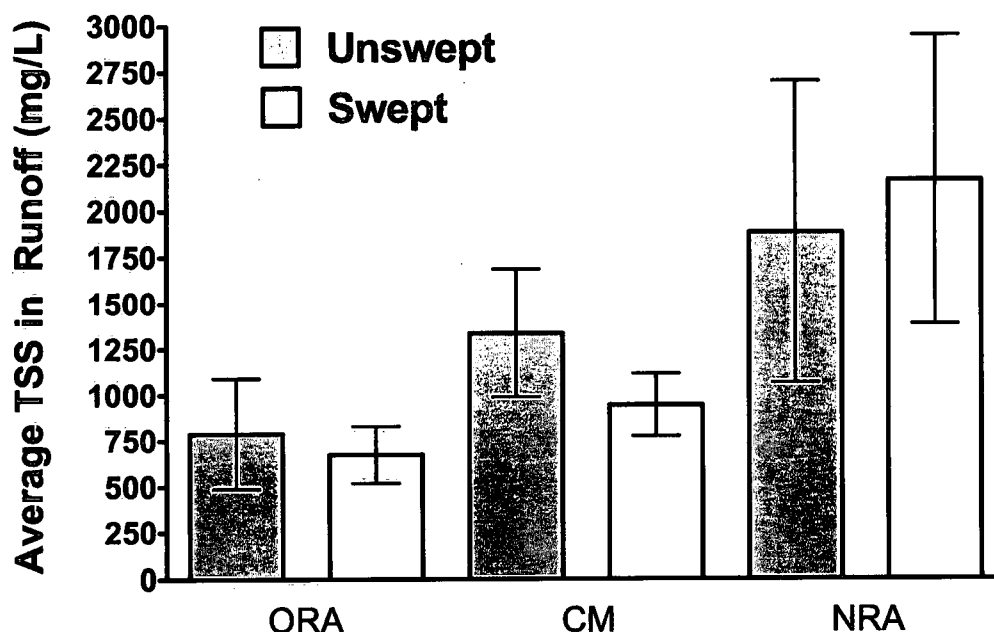


Figure 3.17: Sweeper effectiveness – Changes in Total Suspended Solids (TSS)

The TSS values of samples collected from the catchbasin provide an index for the ease of which the solids could be washed off the catchment test area. However, since the water volumes used to wash down the catchment area were not consistent each time, a more realistic evaluation would be to use the total solids washed off the catchment. This value

was obtained by multiplying the TSS concentration by the water volume used to wash down the test area (in 3 cases, where volumes were not available, they were estimated to be 100 L). This assumes that TSS values account for all solids in the catchbasin; some larger solids which settle out quickly may not have been included in this estimate. As can be seen in Figure 3.18, the solids washed off were relatively unchanged by sweeping, regardless of method. However, both the old regenerative air and the conventional mechanical sweepers showed a tendency towards reducing the solids in the runoff, whereas on northbound lanes, the new regenerative air sweeper appeared to show increasing trends. The results for the new regenerative air sweeper in the southbound lanes showed a very minor (and not significant) reduction in solids.

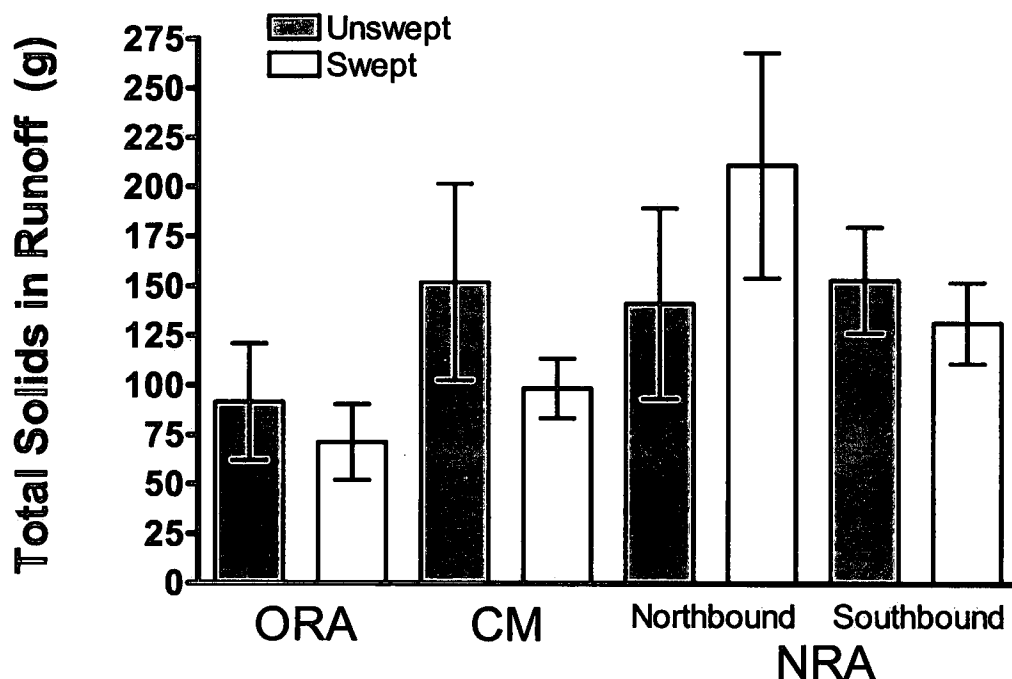
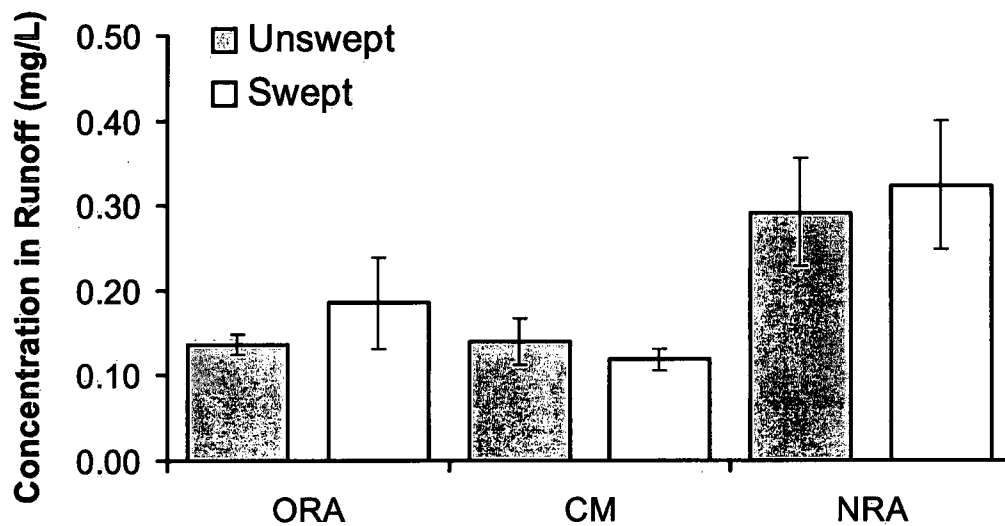
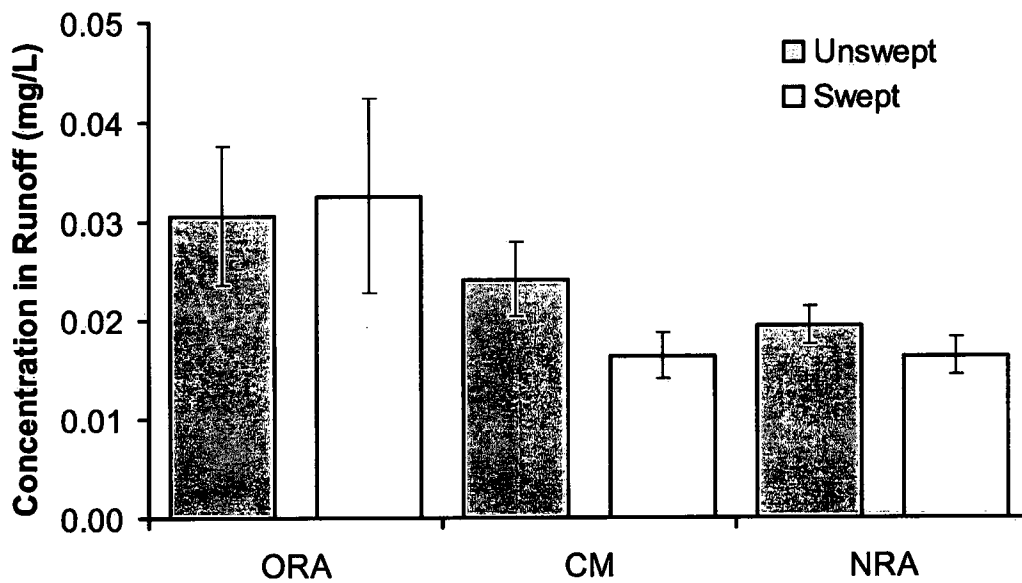


Figure 3.18: Sweeper effectiveness – Changes in total solids washed off

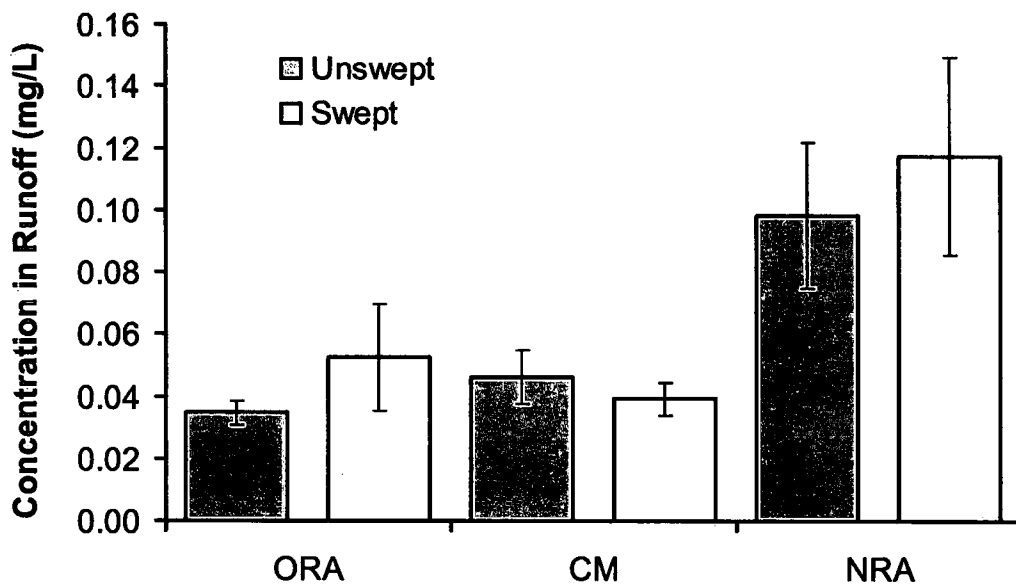
Since none of the sweepers were able to reduce the solids washed off the road surface, it was assumed that there would also be relatively little change in the chemistry (metals and PAHs) associated with this runoff. The initial analysis of water chemistry results has focussed on selected total and soluble metals and the three ubiquitous PAHs. Total copper (Figure 3.19) and dissolved copper (Figure 3.20) showed no change after cleaning with any of the sweepers. Similarly, total chromium (Figure 3.21), total nickel (Figure 3.22) and total lead (Figure 3.23) did not show any changes after sweeping; typically these metals are bound to solids. It can clearly be seen from these figures, that no sweeper could provide any significant reductions in total metals. Interestingly, while total zinc (Figure 3.24) showed no change, dissolved zinc (Figure 3.25) showed reductions of 46% for the old regenerative air and 56% for the new regenerative air. Since Zn has been identified as a toxic metal in urban runoff, the reduction of Zn was seen as an important result (Tiefenthaler et al., 2001).



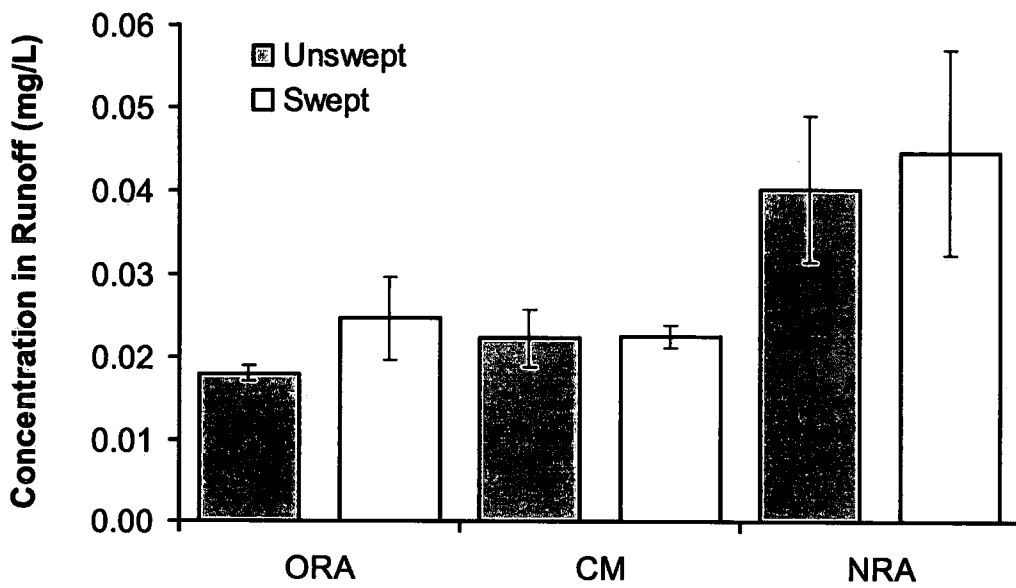
**Figure 3.19:** Sweeper effectiveness – Changes in total copper in runoff



**Figure 3.20:** Sweeper effectiveness – Changes in dissolved copper in runoff

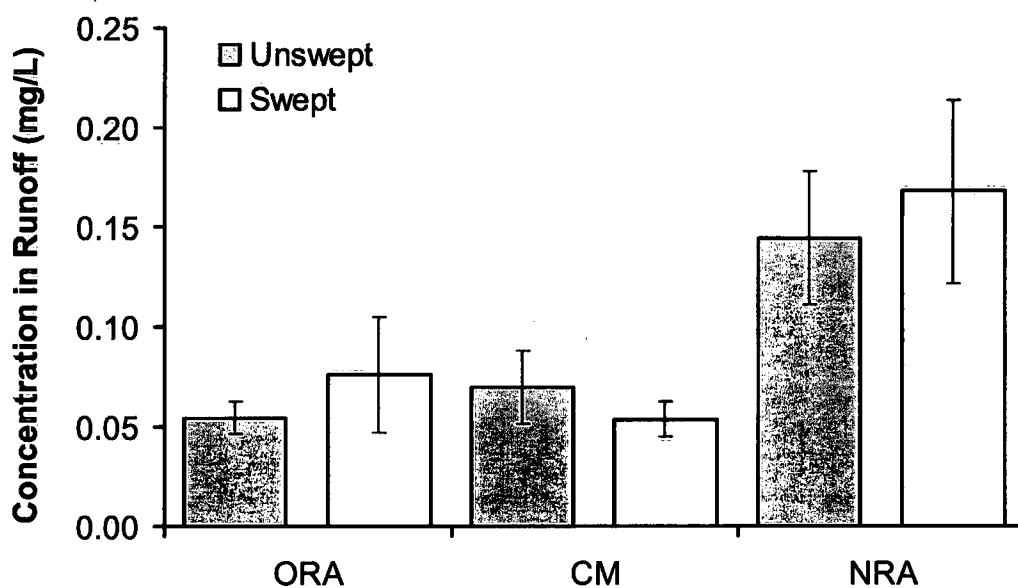


**Figure 3.21: Sweeper effectiveness – Changes in total chromium in runoff**

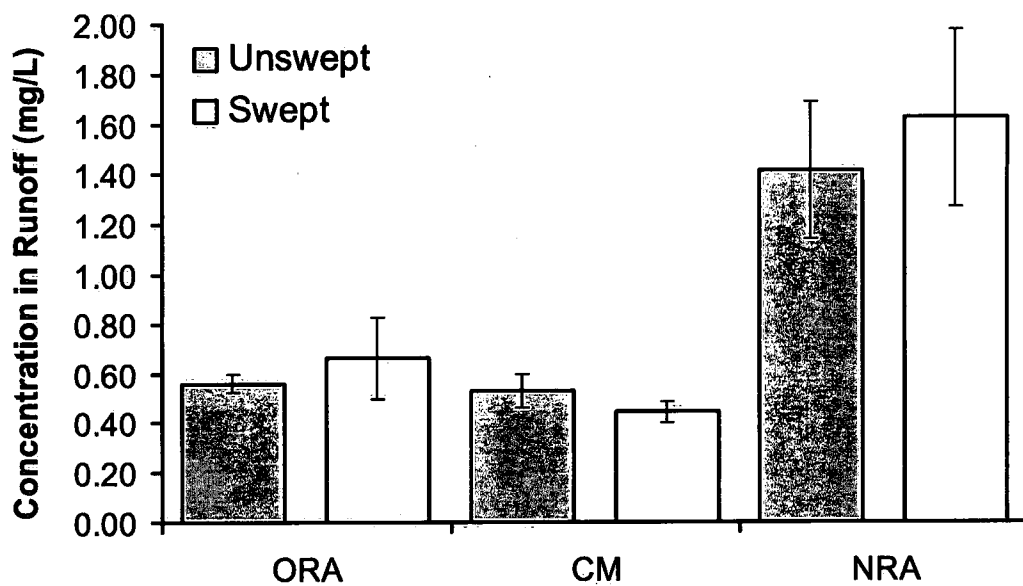


**Figure 3.22: Sweeper effectiveness – Changes in total nickel in runoff**

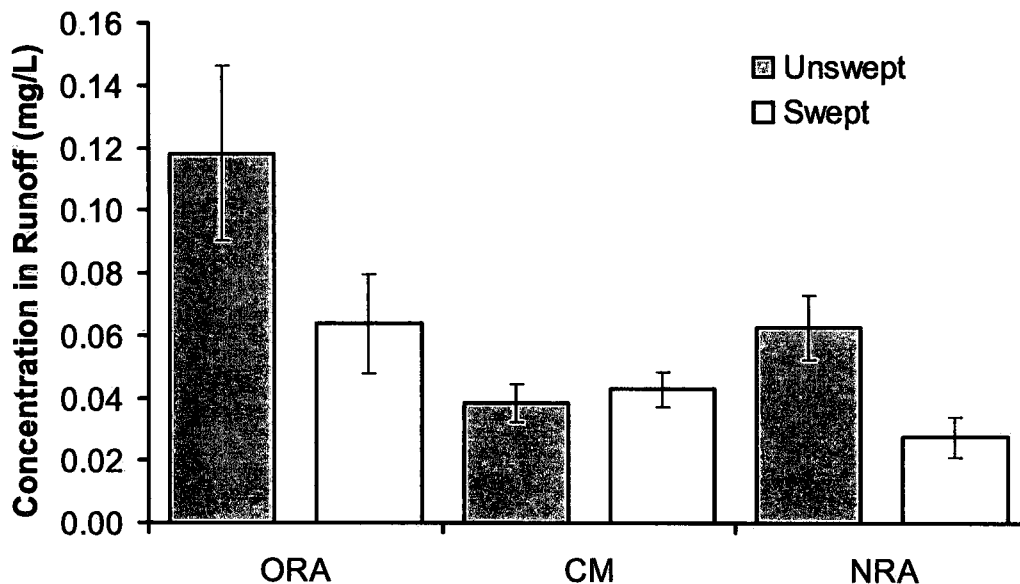




**Figure 3.23: Sweeper effectiveness – Changes in total lead in runoff**

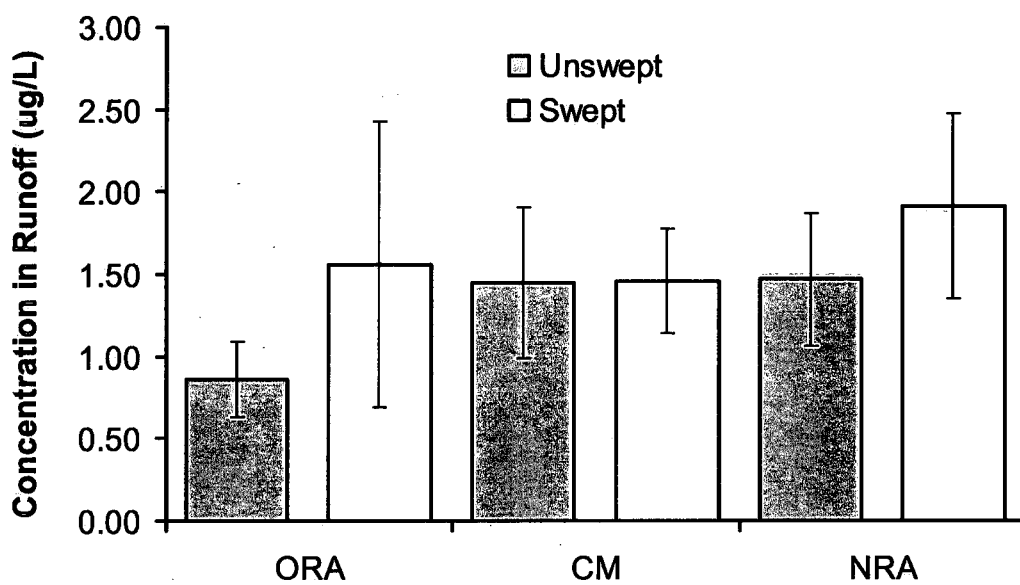


**Figure 3.24: Sweeper effectiveness – Changes in total zinc in runoff**

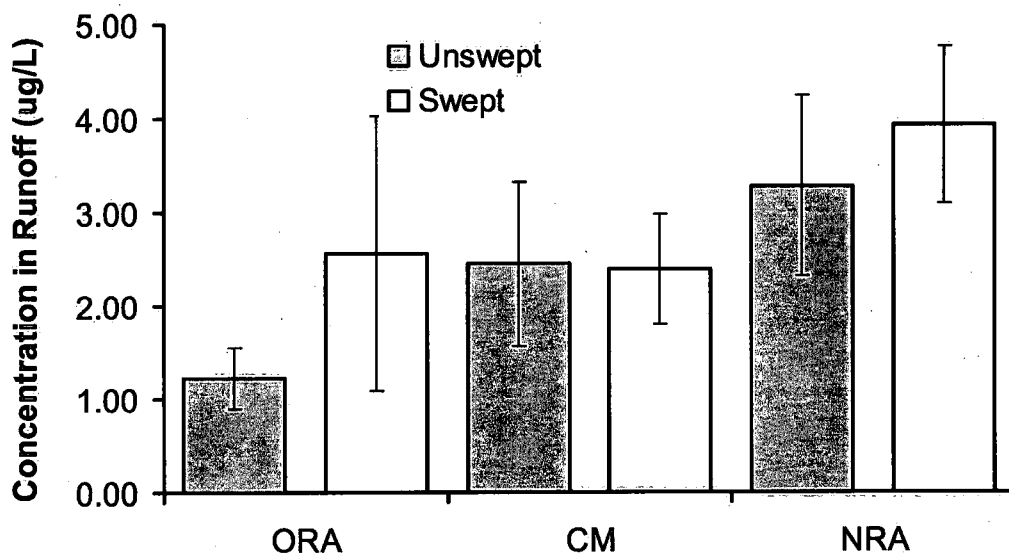


**Figure 3.25:** Sweeper effectiveness – Changes in dissolved zinc in runoff

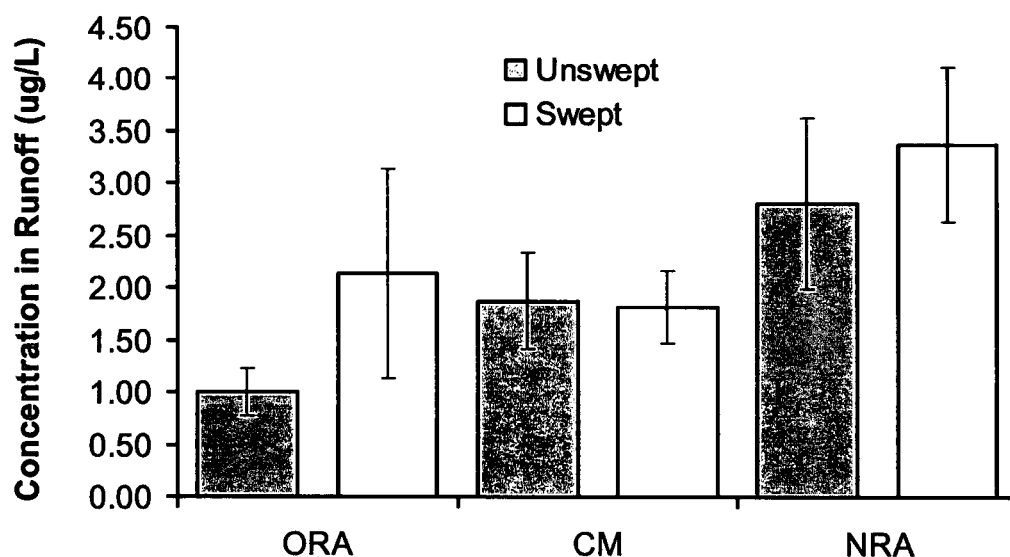
Selected Polycyclic Aromatic Hydrocarbons (PAHs) were also compared to determine if there were any changes in runoff concentrations as a result of sweeping. Phenanthrene, fluoranthene and pyrene were selected (from the 16 U.S. EPA priority PAHs originally analyzed) for an initial comparison. Figure 3.26 shows the effect of the three sweepers on phenanthrene, Figure 3.27 shows the effect of the three sweepers on fluoranthene and Figure 3.28 shows the effect of the three sweepers on pyrene concentrations in the simulated runoff. It can be seen that the PAH concentrations varied considerably and while no significant changes were noted, in some cases, swept sites appeared to have insignificantly higher PAH concentrations on average.



**Figure 3.26: Sweeper effectiveness – Changes in phenanthrene concentrations**



**Figure 3.27: Sweeper effectiveness – Changes in fluoranthene concentrations**



**Figure 3.28:** Sweeper effectiveness – Changes in pyrene concentrations

### 3.3.2 *Effects of street sweepers on runoff toxicity*

Runoff toxicity was evaluated by three acute toxicity tests which have been shown in past studies by Marsalek et al. (1999) to provide a wide range of ecotoxicological responses to urban pollution. Of the three tests which were applied, the 96-hour Rainbow trout LC50 test, was found to be the most sensitive at detecting impacts in this case. Figure 3.29 shows the impact that the three street sweepers had on the toxicity of the artificially generated runoff. Rainbow trout toxicity results were highly variable for all sites and during the 2005 testing, very little toxicity was encountered. In Figure 3.29, the toxicity is defined by the lethal concentration required to kill 50% of the population and is expressed as LC50. When the LC50 is 100% (or greater), it is an indication of no toxicity. As the LC50 value decreases, the severity of the toxicity increases. For comparison purposes, a “fail” in this test is considered to be  $LC50 < 50\%$ . None of our tests showed this acute level of toxicity. This may have been due to considerable rainfall (and therefore a lack of dry days over which to build up the pollutants) during the test period. Although the difference was not very great, the new regenerative air machine was the only one which provided a reduction in the toxicity of the runoff.

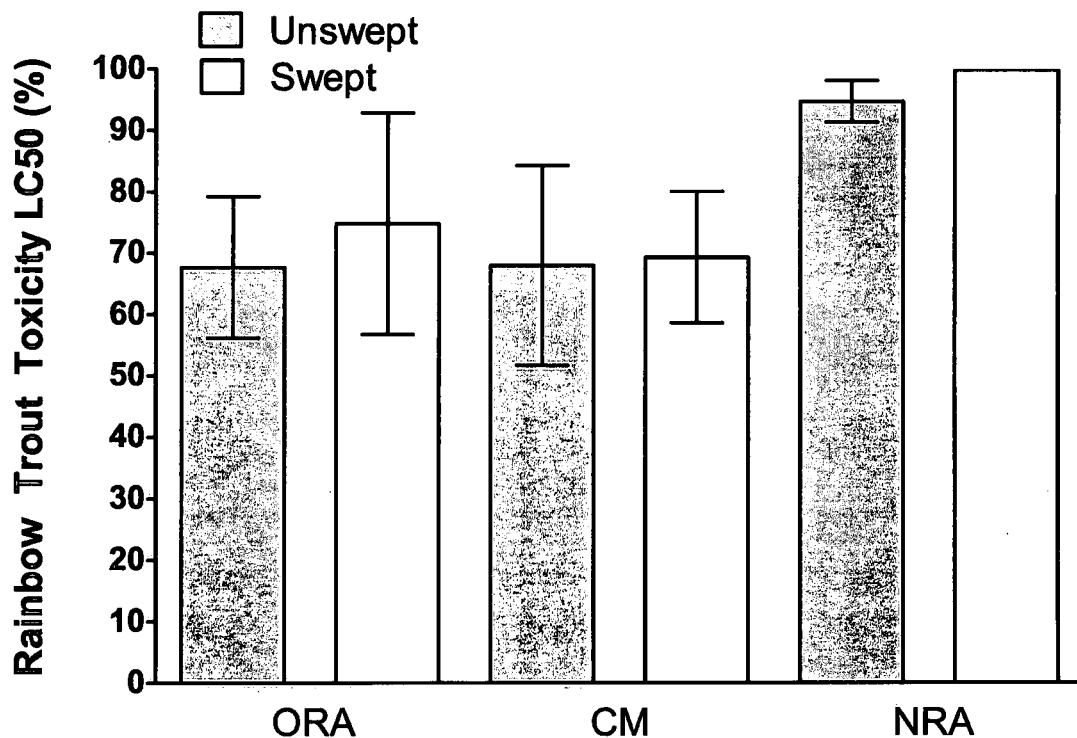
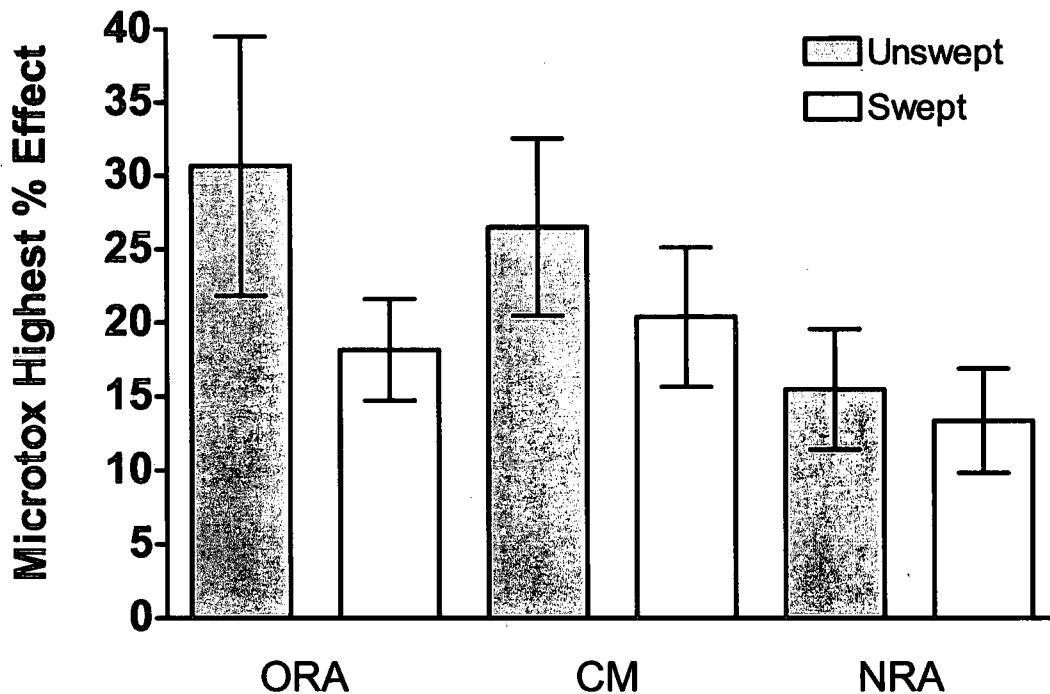


Figure 3.29: Sweeper effectiveness – Changes in toxicity to Rainbow trout (Note: 100% is non-toxic)

It was interesting to note that the 96-hour acute *Daphnia magna* LC50 test did not show evidence of any toxicity. All of these test results showed 100% survival.

The standard Microtox™ 15-minute acute toxicity test did show some slight toxic responses for these street sweeping samples tested, however, not all samples were toxic enough to allow an EC50 to be calculated. In order for samples to be compared, the percent effect value, which was calculated in all cases, was used instead. Percent effect measures the effect of the raw sample on light output. The bioluminescent bacteria (*Photobacterium phosphoreum*) used in the Microtox™ test reduce their light output as the level of toxicity in the sample increases. On this scale, zero percent would indicate no effect; as the percent effect climbs, so does the toxicity. Figure 3.30 shows the percent effect for Microtox™ 15-minute acute test samples. The most toxic samples were found in the northbound unswept runoff in 2004. The corresponding swept site runoff showed reduced toxicity, which was just outside the standard error, suggesting that this could be a significant result. Although the trends for both the conventional mechanical and the new regenerative air sweepers did show trends (on average) towards reducing the toxicity, none of these results was considered significant.



**Figure 3.30: Sweeper effectiveness – Changes in Microtox™ 15-minute % effect**  
 (Note: % effect is the reduction in light output and therefore greater % effect is more toxic)

### 3.4 Summary of Results

A brief summary of the findings to-date follow. These are only meant to highlight important data from the study.

- In street sediment samples, gravel ranged from 13 to 42%; sand from 55 to 85%; silt and clay from 2 to 6%.
- Mean particle size of the sediment samples from unswept sites was 814  $\mu\text{m}$  northbound and 1048  $\mu\text{m}$  southbound.
- Sediment accumulation rates of 9 to 22 g/curb m/d were similar to literature values (again, construction was expected to influence the southbound lanes).
- Mean sediment loads were on the order of 40 to 160 kg/curb km.

In simulated runoff (wash off) samples:

- Mean particle size for simulated runoff into the catchbasin was 10.8  $\mu\text{m}$  for both the swept and unswept areas. Both methods used to wash off the experimental sites were comparable.
- Overall, the mean for solids washed off from unswept sites was 129 g/80  $\text{m}^2$ ; or just 10-25% of the total mass collected by vacuuming. This would suggest that

only a portion of the material left on the street is actually available for washoff during a rainfall event; the actual amount washed off will vary depending upon the intensity and duration of rainfall (both relatively low in wash off experiments).

- The highest concentrations of contaminants (per unit mass) were found in the <64  $\mu\text{m}$  size in sediment from the unswept area.
- Only the new regenerative air sweeper showed the ability to remove statistically significant mass down to some threshold level. It was also better at removal of (specifically) gravel and sand. Once above a certain threshold, silt & clay removal also appeared to be better for the new regenerative air sweeper than for other types of sweepers.
- Some sweepers actually showed increases in solids during sweeping – perhaps generated by abrasion of street surfaces or brought with the sweepers from other sites (on dirty brooms).
- There was no change between swept and unswept sites in terms of nutrient loads; in fact, some swept / unswept comparisons showed some increases after sweeping.
- No sweeper demonstrated an ability to reduce the TSS in runoff. This may support the hypothesis that the sweepers can only pick up so much material; below a certain level of solids, sweepers may be ineffective, leaving the fine residual material which is then available for washoff during rainfall events.
- The new regenerative air sweeper was much more consistent in its ability to reduce total solids on the road.
- Dissolved zinc was reduced by the regenerative air sweepers, but not by the conventional mechanical sweeper.
- PAHs appeared to be relatively unaffected in sweeping, although the old regenerative air sweeper did appear to release some PAHs during sweeping (this may have been due to transport of PAH contaminated dirt from outside sources into the test area).
- Overall, runoff toxicity was low. Given the 26,000 vehicle / day traffic volume is below the suggested 35,000 vehicle / day threshold for acute effects to appear, this result may not be unusual. It is also possible that inert sediment from construction areas was responsible for this reduced toxicity. Additionally, higher than normal rainfall may have resulted in washoff of more toxic materials from the test areas prior to sampling.

## 4 DISCUSSION

### 4.1 Characterization of Road Deposited Sediment

In the characterization of the road deposited sediment from this site on Markham Road, it was determined that the material deposited on the street was typical of other commercial / industrial sites (Stone and Marsalek, 1996; Pitt et al., 2004). It was also found that the material collected was highly variable in terms of total mass and composition (fractions of gravel, sand and silt+clay). The lack of consistency in the unswept conditions made effectiveness comparisons between sweepers more challenging. Part of this variation may have been due to wind transport (removal and deposition of fine material), traffic effects, intensity and frequency of rainfall events and construction activity (Breault et al., 2005). The composition and volume of road dust along the southbound lanes was likely amended by the construction material transported in from further north and both sides of the street were influenced by the presence of construction traffic. The dominance of the sand fraction (approximately 55% or greater) and low amounts of silt & clay (< 6%) meant that the effectiveness of the sweepers was largely based on their ability to pick up sand and gravel.

The mass of solids and associated pollutants on the road surface, which is available to be washed off from urban streets, is important for determining pollutant loads washed off by stormwater to downstream treatment facilities and receiving water bodies. The intensity of the storm will affect the total mass and size of particles washed off and carried into the receiving environment (Novotny, 2003). By reducing the amount of material available at the source, downstream water quality should be improved. Once a runoff event occurs, the material may be transported directly to the receiving waters, or stored in catchbasins, oil & grit separators or stormwater management facilities, where it may undergo further transformations and leaching or burial by inert sediments may occur. Without routine maintenance of these structures and facilities, the receiving waters can become increasingly degraded.

The methods used to simulate runoff in this study reproduced a reasonably consistent low-intensity runoff from a "storm" event so that the variation in runoff quality would be attributable directly to the effects of the sweepers and/or source material. Although every effort was made to minimize the differences in generating this runoff in individual experimental runs, the variation in the techniques applied (a garden hose rain nozzle vs. light-pressure water broom) and the use of different wash down operators (each with subtly different techniques), may have contributed some variation to the results. Even though the results showed that the wet sampling methods were comparable in terms of the mean particle size in simulated runoff samples, the mean particle size on the northbound lanes did increase slightly, which may have been the result of a more efficient washing technique representing higher equivalent rainfall intensity.



## 4.2 Effects of Street Sweepers on Road Deposited Sediment

A reduction in the overall mass of road deposited sediment could only be achieved by the new regenerative air sweeper. None of the other sweepers could achieve a significant reduction in this parameter. However, this 67% removal was only achieved along the southbound lanes (with higher accumulations of material), whereas the northbound lanes actually showed an 18% increase in road deposited sediment. It is possible that for sweepers in general, under real-world operating conditions, a threshold exists, below which removal is not normally possible. If the sweepers were to be compared under "lab-type" conditions, where factors such as wind, outside debris and sweeper cleanliness could be controlled, these statistics may improve.

When analyzing the results of the mass of gravel, sand and silt & clay particles removed from the road surface, it appeared that the new regenerative air sweeper was able to provide a consistent reduction in the quantities of all of these particles. It was also noted that there appeared to be a limit, beyond which, the sweeper could not remove additional particles. This was most notable for the northbound lanes, where little effect was seen for anything except gravel. Particle size in general was also reduced best by the new regenerative air sweeper. The conventional mechanical sweeper was able to achieve some reductions, largely due to removal of the larger gravel fractions, but it still left a considerable portion of sand and silt & clay on the road surface. Advances in sweeper technology (e.g., now, regenerative air equipment is available to meet PM<sub>10</sub> and PM<sub>2.5</sub> specifications) along with improved street sweeping techniques and practices, reductions of this background level should be achievable (to approximately 10 kg/curb km) to the point where there would be much less material available to be washed off.

## 4.3 Effects of Street Sweepers on the Quality of Simulated Runoff

The results from runoff chemistry analyses were highly variable. As a consequence, differences in the effectiveness of the three types of sweepers, measured by comparing washoff chemistry and toxicity for swept and unswept site pairs, were much more difficult to determine. No sweeper was able to provide a consistent removal of solids available for washoff and in some cases increased solids washoff was noted after sweeping. Similarly, the total metal and PAH chemistry of swept and unswept sites was not significantly different. This suggests that the sweeping practices used in this study did not alter the pollutant load susceptible to washoff to a large degree, but did improve the safety (by removing sand and gravel which could cause vehicles to skid) and aesthetics (by removal of litter and large debris) of the street. The fact that some parameters such as dissolved Zn (a known toxicant) were reduced by the regenerative air machines, suggested that these sweepers could still have a beneficial effect on the total loads on the receiving environment. Further work, under optimal conditions would be needed to confirm these findings.

The toxicity results were surprising for a commercial / high-traffic area such as Markham Road. The complete lack of toxicity to *Daphnia magna* was unusual, since in previous

studies, *Daphnia magna* has reacted quite strongly to urban runoff pollution (Marsalek et al., 1999). The 96-hour Rainbow trout LC50 and Microtox™ EC50 15-minute tests (using % effect rather than EC50 values), appeared to be the most sensitive tests to apply at this location in terms of identifying changes in the toxicity of runoff. Even so, only limited differences were discernable at best. Swept sites were generally less toxic than the unswept sites, although since the variation in the results was so great, statistically significant results were difficult to determine.

Transfer of solids from other locations is a potential problem in the operation of these sweepers. It is likely that the November 10, 2004 sweeping operation had a much higher level of contamination than on other test dates since street sweeping operations were being performed in residential areas to clear up leaf debris. This additional material is likely the source of the solids contamination for the runoff TSS and street dry sampling. The recommendation for future testing was to pre-clean the sweeper and then provide a “clean” area to run the sweeper as a warm-up loop, to ensure that contamination would be minimized. Sampling in 2005 suggests that this transfer of solids from outside sources was no longer a problem.

#### **4.4 Street Sweeping Issues**

Some Municipalities regard street sweeping as a form of litter control, while others apply sweepers as a first line of defense for stormwater best management practices (as source control measures). Resource availability and funding, in a large part, dictate how intensive and successful the sweeping programs can be. Optimizing the frequency of sweeping, depending upon the traffic volume and type of area being swept (residential, commercial or industrial) and frequency of local rainfall events would also maximize benefits. The frequency of sweeping may change over the course of the year, more often (e.g., in springtime) to prevent winter accumulations of sediment from spring washoff. Other optimizations include targeting specific areas more frequently (e.g., construction traffic, heavy industrial areas with wind-borne transport of dusts, etc.) and sweeping prior to rainfall events, can increase the effectiveness of the street sweeping program. Even parking enforcement programs to maintain roadways clear of parked cars during sweeping operations can have beneficial effects (Stidger, 2003). Selecting the right sweeper and operation mode (dry / dust suppressing with water / no dust suppression, etc.) may also impact the effectiveness in terms of fine particle pickup. Depending upon the situation, conventional mechanical sweepers or high-efficiency regenerative air sweepers or a combination of the two may offer the best options for a particular application.

Industrial areas (such as North Hamilton, ON) may benefit from a more rigorous cleaning schedule of 3 times per week (Stidger, 2003) to reduce airborne particulate transfer and prevent it from entering the receiving waters. Since many areas also identify fine particulate material as affecting air quality, the frequency, time of day and type of sweeper used will impact the effectiveness of the sweeping program. Cleaning schedules of only once per month may not achieve any benefits aside from litter control.

Stidger (2003) reported a number of best sweeping practices, adapted from St. Paul, Minnesota. These included the proper training of operators and maintenance workers, optimizing shifts, use of sweepers/equipment which feature time-saving and cost-saving accessories (e.g., bin-clearing methods and locations), sharing of equipment with other municipalities, monitoring equipment costs and maintenance records, using double shifts in springtime to maximize cleanup effectiveness and using multiple sweepers in tandem operation to clear larger areas quickly.

In a study by the Terrene Institute (1998), it was reported that the advancement in street sweeping technology had increased dramatically since the results of the EPA's Nationwide Urban Runoff Program (NURP) study were published. Sweepers that can operate in a dry mode and / or use minimal water for dust suppression in combination with dustless technology were favoured to collect road dust, since they would not leave a film of mud (wet dust) on the road after passing by; this is a common problem with sweepers which rely solely on water to suppress dust. Street sweepers need to be adjusted for various modes of operation, such as dry, heavy silt, wet conditions, leaves, large debris and fine particulate matter. These conditions need to be considered when determining the frequency and the sweeper's operational mode. It was also noted that self-cleaning filters (using compressed air) maintained the vacuum efficiency without having to stop and perform a cleaning function which further saves operational time. Under certain conditions tandem sweeping can be applied in order to maximize removal of surface sediment. The new technology regenerative air street sweepers are very diverse and can operate achieving high efficiency in silt removal from the paved surface of the road under various modes of operations. The cost of the increased street sweeping effectiveness was identified as a critical factor in decision making, since cleanup (dredging operations) of creeks and sewer pipes due to solids washing off roads could consume a larger proportion of budget than purchasing and maintaining a high-efficiency sweeper.

Street sweeping can be cost effective in stormwater management, though the benefits are hard to prove. Sweeping is a management measure with immediate benefits; other measures, like ponds, can take years to build and significant investments of time and money are required to construct, monitor and maintain. Stopping pollutants at the source removes the pollutant before it is exposed to rainwater and prevents further transport in either solid or dissolved forms. Since the pollutants in street residue removed during dry weather are never transformed into dissolved forms, which are much more difficult to treat, they are much easier to manage. Street sweeping can be most effective if streets are free of parked cars, in commercial or industrial areas, where pollutants are more prevalent, but becomes more difficult in residential areas with on-street parking (Stidger, 2003).

The costs associated with street sweeping differ for each municipality, however some examples as given by the City of Hamilton, (Ontario, Canada) and the City of Toronto (Ontario, Canada), suggest that these operation and maintenance costs do not burden the annual budgets when compared to the cost of purchasing the actual equipment, which can range from more than \$150,000 for used equipment to more than \$300,000 for PM2.5

certified regenerative air sweepers. (Stevanovic-Briatico pers. comm.). The reduction in costs associated with maintenance of stormwater management facilities and structures would have to be weighed against the increased costs of the higher-efficiency sweepers. However, the fact that these sweepers, if used effectively, could also provide an enhanced environmental benefit should also be considered.

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

The objective of this study was to assess the potential of street sweeping to improve stormwater runoff quality, investigating three types of street sweepers currently used in Toronto. Effective street sweeping represents one of many potential management measures being considered for implementation by the Toronto Wet-Weather Flow Management Master Plan contributing to remedial action in the Toronto Waterfront Area of Concern. Recognizing the experimental difficulties and the use of older, less efficient sweepers in the earlier studies of street sweeping, a new approach was adopted for this study for assessing environmental benefits of sweeping, using both toxicity and chemistry to evaluate the changes in runoff from both swept and unswept test areas. Within the limitations of this study and the realm of experimental uncertainties, the results indicated that the new regenerative air sweeper did provide some key benefits, including a reduction of the total mass of solids on the street and a reduction of dissolved Zn. The old regenerative air sweeper provided a similar reduction for dissolved Zn, but was not as effective in removing solids from the street. The conventional mechanical sweeper did reduce the mean particle size of solid residue after sweeping, but no environmental benefits were observed. The total suspended solids concentrations in washoff applied in this study were not changed by sweeping for any of the sweepers tested. No toxicity was noted for *Daphnia magna*, and only limited toxicity was evident for Microtox™. None of the sweepers demonstrated a (statistically) significant reduction of runoff toxicity, although swept sites were always slightly less toxic than the unswept ones. The test data showed only limited improvements for runoff from catchments swept using regenerative air sweepers. Potentially, the high-efficiency regenerative air sweepers may be more effective in improving air quality (when compared to older type sweepers) than they are able to do for runoff quality. However, if the equipment was well-maintained and used frequently enough, it could provide a viable source control measure and be beneficially applied to areas of concern.

### 5.2 Recommendations

The study results suggest that advanced street sweepers remove significant quantities of street residue and should be able to reduce the toxicity and chemical impacts of urban wet-weather pollution by acting as a source control measure. The key to improving the effectiveness of such a source control measure is the way in which it is applied. In order to be effective as a means of source control, sweeping must be done with the most efficient sweepers available as often as practical (and affordable), and prior to a rainfall event. The sweepers must be clean and well maintained in order to operate at peak efficiency. Operators must be properly trained and fully familiar with the machines in order to obtain the best performance. Experience with the latest advances in sweeping methods (e.g., when to apply "dustless" sweeping, how much water to apply and where etc.) become issues which could contribute incremental differences in the efficiency of the sweeper. Areas where pollution levels are highest and access is easier (i.e., the arterial network and industrial areas) are most suitable for frequent sweeping. Loadings

from residential areas are less contaminated and while it may be desirable to remove the fine material from these roads, it should be given lower priority than other areas. Sweeping programs which target the winter-accumulated material on the road prior to the spring rain storms would also be most effective and a quick execution of such a program, e.g., by working extra shifts, may be desirable during this period. With well-maintained equipment and frequent sweeping with the most efficient sweepers, operated by skilled personnel, street sweeping should provide a suitable means of source control in urban wet-weather pollution. The costs associated with these requirements need to be factored in to long-term plans for wet-weather flow management.

### **5.3 Future Work**

Future considerations for field research include the testing of the most recently purchased, clean equipment which is in peak working order. Since highly-specialized modes of operation are only used infrequently, it would be recommended that the "standard" mode of operation be utilized for testing, which includes the use of gutter brooms to collect gutter debris and water sprays to suppress dust. Continuing to use toxicity testing to evaluate sweeper effectiveness would also be recommended, since the toxicity of runoff is the best measure of the effectiveness of the sweeper at reducing the potential for toxic substances from being mobilized during wet weather.

## **6 ACKNOWLEDGEMENTS**

Funding for this project was obtained from the City of Toronto, Toronto Water and the Transportation Services Division in support of the implementation of the City of Toronto Wet Weather Flow Master Plan. Additional funding was made possible through The Government of Canada's Great Lakes Sustainability Fund.

The authors would like to thank many collaborators who have contributed their expertise and advice to the planning and implementation of this project. Without their hard work, this research would not have been possible. These people include: Dr. Peter Seto, NWRI-Burlington, Mr. Brian Taylor, Mr. Bill Warrender, Mr. Steve Smith – Technical Operations Group, Environment Canada, Mr. Steven Kydd, Mr. Doug Doede and a number of co-op students – NWRI, Burlington, Mr. Dave Poirier, Ms. Melanie Appleton and Mr. Richard Chong-Kit – Ontario Ministry of Environment, Mr. Keeva Lane, Mr. Matthew Lee, Mr. Nazzareno Capano, Mr. Rob Burlie, Mr. Andrew Particka, Mr. Shane Moonah, Mr. Jonathan Tang – Transportation Services Division, and Mr. Michael D'Andrea, Mr. Patrick D. Chessie, Dr. Jian Lei and Ms. Wanda Jakobczyk of Toronto Water and Dr. Christopher Morgan – Environmental Services Division, City of Toronto.

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## APPENDIX A

**Table A1: Proposed sampling and reasons for re-scheduling**

Proposed sampling date	Sampled? (Y/N)	Reason for not sampling / Notes
Tuesday 19 July, 2005	N	Rainfall on 17 July of 27 mm (< 5 days prior to sampling)
Wednesday August 3, 2005	N	Rainfall on 1 August of 15 mm (< 5 days prior to sampling)
Tuesday August 9, 2005	Y	First sweeping test (used old water broom nozzles)
Tuesday August 23, 2005	N	Rainfall on Sunday and Monday forced cancellation of sampling
Tuesday August, 30, 2005	Y	Second sweeping test
Tuesday September 13, 2005	N	Sweeper compressor broke down Monday, September 12, 2005 – repaired by 16 September, 2005 – had to cancel sampling at last minute
Tuesday September 20, 2005	N	Rainfall on 14 September of 13.2 mm and 16 September of 24.6 mm plus forecast of rain and thunderstorms on Monday night and into Tuesday <i>(In fact, the T-storms missed our site and no rain fell on Mon/Tues)</i>
Thursday September 22, 2005	N	Sweeper not available & Traffic control not available at short notice
Monday September 26, 2005	N	Sweeper in use at DISCO YARD all other days of the week This would be first test after sweeper had been rehabilitated. Cancelled due to Hurricane Rita and heavy rains
Tuesday October 4, 2005	Y	OK – went well – noticed some improvement in effectiveness of sweeper – new driver used and water used to suppress dust on NBSW.
NOTE		From MOE – not allowed to submit samples after Thursday due to extreme load in lab
Wednesday October 12, 2005	N	Rain / drizzle (low level) all day for several days
Tuesday October 18, 2005	N	Not enough personnel available from TOS or UWMP.
Wednesday October 19, 2005	N	100% chance of rain forecast (in fact it did rain at about 11am for short duration but highly intense thunderstorms)
Thursday 20 October 2005	N	No traffic control available (plus strong chance of rain)
Tuesday 25 October, 2005	N	Availability of traffic control crew in question.
Thursday 27 October, 2005	Y	Last sampling event of the season. SBSW used as test area for dust control water sprays.

## **APPENDIX B**

### **Road Deposited Sediment Chemistry**

#### **List of Tables:**

Table B1: Road Deposited Sediment – Nutrient Chemistry

Table B2: Road Deposited Sediment – Metals Chemistry

Table B3: Road Deposited Sediment – PAH Chemistry

**Table B1: Road Deposited Sediment – Nutrient Chemistry**

Units	24-Aug-04				14-Sep-04				23-Sep-04			
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
TOC (solid) %	3.2	1.2	3.3	1.1	2.6	1.1	2	0.9	3.8	1.4	3.8	1.6
TKN (as N) mg/kg	1000	260	1200	340	790	290	620	210	1200	410	1300	450
Total Phosphorus (as P) mg/kg	810	590	900	590	710	500	810	570	810	540	850	510
Total Weight of solids g	743.0		451.0		1964.0		3317.5		768.5		516.5	

Units	7-Oct-04				10-Nov-04			
	SBSW		SBUS		NBSW		NBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
TOC (solid) %	2.6	1.6	2.3	0.9	3.4	1.1	3.9	1.5
TKN (as N) mg/kg	1200	610	990	290	950	280	1100	270
Total Phosphorus (as P) mg/kg	620	450	630	360	720	530	720	430
Total Weight of solids g	1105.0		1324.0		1438.0		1303.5	

Units	9-Aug-05								30-Aug-05							
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS		SBSW		SBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
TOC (solid) mg/kg	43000	14000	42000	13000	30000	11000	24000	9000	21000	12000	42000	47000	38000	13000	32000	12000
TKN (as N) mg/kg	795	725	824	356	774	197	613	160	1060	204	946	234	936	348	957	143
Total Phosphorus (as P) mg/kg	760	430	810	540	750	430	930	520	880	460	1000	520	710	370	980	500
Total Weight of solids g	708.5		592.0		1059.5		5426.5		1170.5		824.0		933.5		1407.5	

Units	4-Oct-05								27-Oct-05							
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS		SBSW		SBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
TOC (solid) mg/kg	42000	17000	49000	13000	35000	12000	26000	15000	54000	24000	47000	14000	42000	24000	32000	11000
TKN (as N) mg/kg	795	725	824	356	774	197	894	156	939	378	780	210	972	369	759	194
Total Phosphorus (as P) mg/kg	690	510	750	520	770	480	850	430	630	430	720	390	660	480	720	410
Total Weight of solids g	771.5		494.0		975.0		2758.5		580.5		832.5		1073.5		3143.5	

**Table B2: Road Deposited Sediment – Metals Chemistry**

Units	24-Aug-04				14-Sep-04				23-Sep-04			
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
Aluminum ug/g	4800	1900	4700	1800	5500	2100	5300	5000	5000	2000	4800	1900
Antimony ug/g	1.8	0.7	2	4.4	1.4	0.5	1.2	1.9	1.9	0.7	2.1	5.7
Arsenic ug/g	2.5	1.5	2.1	1.7	2.3	1.3	1.9	2.2	2.8	1.4	2.5	1.9
Barium ug/g	150	45	160	52	150	50	140	160	160	59	150	81
Beryllium ug/g	0.3	0.2	0.3	ND	0.3	ND	0.3	0.3	0.3	0.2	0.3	0.2
Bismuth ug/g	0.3	ND	0.4	0.2	0.2	ND	0.2	0.3	0.3	ND	0.2	ND
Boron ug/g	5.9	ND	7.8	2.3	6.2	ND	4.3	5.5	6.2	ND	7.2	ND
Cadmium ug/g	0.9	0.3	0.8	0.2	0.6	0.2	1	1	0.8	0.3	0.8	0.3
Chromium ug/g	81	89	77	86	69	57	50	75	74	63	67	50
Cobalt ug/g	6.8	3.3	5.9	3.5	7.5	3.4	5.1	7.8	8.4	3.5	5.7	4
Copper ug/g	160	170	140	86	130	110	120	300	310	190	260	180
Iron ug/g	25000	18000	19000	19000	29000	17000	17000	26000	27000	17000	19000	16000
Lead ug/g	71	24	61	210	57	29	41	65	63	26	65	350
Manganese ug/g	780	400	850	400	760	500	600	740	740	370	660	350
Molybdenum ug/g	5.1	3.6	5.1	4.1	4.5	2.8	3.8	5.2	5.1	4.4	5.2	3.6
Nickel ug/g	26	11	22	21	24	9.9	16	28	31	22	25	19
Silver ug/g	0.2	ND	0.2	ND	0.1	1.7	0.1	1.7	1.1	1.6	0.9	0.1
Strontium ug/g	190	160	200	130	200	140	200	180	180	180	190	140
Tin ug/g	13	3.9	9.8	5.2	12	13	9.1	9.9	10	6.6	11	6.5
Titanium ug/g	330	180	330	190	330	180	340	340	350	200	290	170
Uranium ug/g	0.7	0.3	0.6	0.4	0.5	0.3	0.5	0.5	0.5	0.3	0.5	0.3
Vanadium ug/g	20	8.9	20	9.3	21	11	19	22	22	9.6	19	8.7
Zinc ug/g	500	220	540	220	350	210	260	490	490	240	540	270

Units	7-Oct-04				10-Nov-04			
	SBSW		SBUS		NBSW		NBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
Aluminum ug/g	7100	2700	8100	2700	4600	1900	4900	1900
Antimony ug/g	0.8	0.5	1	0.3	2.5	1	2.6	1.6
Arsenic ug/g	2.2	2.2	2.4	1.2	2.3	1.5	2.3	1.9
Barium ug/g	110	45	150	49	170	82	180	59
Beryllium ug/g	0.4	0.2	0.4	0.2	0.3	ND	0.3	0.3
Bismuth ug/g	0.2	ND	0.3	ND	0.3	ND	0.2	1.1
Boron ug/g	5.1	ND	9.8	ND	5.5	ND	5.4	ND
Cadmium ug/g	0.5	0.2	0.6	0.9	0.9	0.4	0.9	2
Chromium ug/g	49	42	42	30	62	42	64	47
Cobalt ug/g	7.1	3.1	6.7	3.1	5.4	3.4	5.3	3.4
Copper ug/g	86	100	86	92	180	140	220	140
Iron ug/g	29000	14000	19000	13000	19000	16000	18000	17000
Lead ug/g	35	17	37	24	70	82	67	64
Manganese ug/g	570	300	590	280	770	510	740	370
Molybdenum ug/g	3.5	2.6	2.8	4.1	5.3	4.6	5.4	3.5
Nickel ug/g	23	11	18	8.6	19	20	20	9.9
Silver ug/g	0.1	ND	0.1	ND	2.8	ND	0.1	ND
Strontium ug/g	160	150	200	130	200	170	200	140
Tin ug/g	5.7	2.2	5.4	3.2	6.9	15	9.5	5.8
Titanium ug/g	360	190	360	170	290	170	270	170
Uranium ug/g	0.5	0.3	0.6	0.4	0.5	0.3	0.4	0.3
Vanadium ug/g	22	9.9	22	8.4	21	9.8	21	8.6
Zinc ug/g	240	160	270	110	410	280	440	200

**Table B2 (Continued): Road Deposited Sediment – Metals Chemistry**

Units	9-Aug-05								30-Aug-05							
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS		SBSW		SBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
Aluminum ug/g	4800	1900	4100	1800	4500	1800	4900	1700	4600	1600	3600	1700	4500	1900	52000	1900
Barium ug/g	150	60	200	80	110	37	120	29	130	37	130	38	130	38	150	51
Beryllium ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium ug/g	0.7	ND	0.7	ND	0.7	ND	1	0.6	1.3	ND	0.5	3.1	1	ND	1.6	0.8
Calcium ug/g	98000	90000	95000	95000	110000	95000	120000	100000	90000	86000	84000	95000	82000	96000	120000	130000
Chromium ug/g	190	130	200	200	130	100	140	130	210	110	230	120	160	81	170	73
Cobalt ug/g	9	5	6	24	6	4	7	5	8	4	9	5	7	3	7	3
Copper ug/g	190	72	200	200	110	58	150	79	200	97	270	100	140	390	190	94
Iron ug/g	60000	39000	36000	64000	49000	32000	37000	41000	70000	33000	62000	48000	62000	28000	41000	37000
Lead ug/g	96	43	84	52	62	40	74	37	97	36	100	74	59	79	78	32
Magnesium ug/g	20000	11000	20000	12000	17000	9800	20000	9200	18000	10000	19000	11000	15000	9800	20000	12000
Manganese ug/g	1100	590	950	860	870	510	830	480	1200	630	1300	620	870	430	930	510
Molybdenum ug/g	7	6	7	11	6	6	4	4	8	6	9	10	6	5	7	5
Nickel ug/g	57	31	52	37	41	25	44	20	63	24	62	30	50	189	48	14
Potassium ug/g	910	440	750	360	770	410	800	360	890	400	1000	650	830	430	890	340
Silver ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND	ND
Sodium ug/g	1300	590	1700	810	760	370	760	280	800	320	730	460	680	330	790	370
Strontium ug/g	210	190	220	240	230	250	310	240	200	160	230	190	190	190	250	210
Sulphur ug/g	2900	1300	2900	1800	2900	1000	3600	1200	2800	1100	3300	1400	2300	670	2800	740
Tin ug/g	ND	ND	ND	ND	ND	ND	ND	120	ND	ND	ND	ND	ND	62	ND	ND
Vanadium ug/g	41	23	38	39	33	22	40	26	49	21	65	25	38	19	46	18
Zinc ug/g	620	260	620	330	400	170	380	180	610	270	610	240	470	240	570	210

Units	4-Oct-05								27-Oct-05							
	NBSW		NBUS		SBSW		SBUS		NBSW		NBUS		SBSW		SBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 64	64-2000
Aluminum ug/g	4100	1900	3900	1700	5100	1900	570	1800	4800	1900	4800	1800	5400	2300	5900	2100
Barium ug/g	160	54	160	41	140	43	190	58	150	44	130	35	140	46	140	38
Beryllium ug/g	0.5	ND	ND	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium ug/g	1.2	0.8	1.1	ND	1	ND	0.7	ND	0.5	ND	0.7	ND	0.5	ND	0.6	ND
Calcium ug/g	100000	110000	120000	100000	110000	100000	120000	110000	130000	92000	120000	90000	140000	88000	120000	92000
Chromium ug/g	160	110	150	110	160	72	160	77	160	81	140	51	110	63	91	41
Cobalt ug/g	7	8	7	5	7	4	7	4	6	3	5	3	6	3	5	2
Copper ug/g	280	470	300	300	180	67	210	100	200	70	210	39	120	61	120	49
Iron ug/g	46000	46000	37000	48000	49000	32000	34000	35000	38000	23000	26000	18000	26000	18000	21000	14000
Lead ug/g	72	96	82	40	67	12	70	19	60	150	60	28	53	30	45	27
Magnesium ug/g	18000	11000	22000	11000	17000	11000	20000	11000	22000	10000	23000	9300	17000	9600	19000	8600
Manganese ug/g	830	600	930	650	780	430	790	470	830	460	760	360	640	370	630	350
Molybdenum ug/g	6	5	5	6	5	4	7	4	7	7	6	3	5	3	4	3
Nickel ug/g	61	85	55	35	59	21	57	26	57	17	51	14	37	19	32	12
Potassium ug/g	810	540	780	460	870	430	910	420	830	460	920	490	910	390	1000	440
Silver ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sodium ug/g	810	480	970	510	710	300	620	260	570	300	640	260	440	240	330	180
Strontium ug/g	180	190	210	160	200	160	230	180	180	130	170	130	200	140	180	130
Sulphur ug/g	2100	1400	2500	1300	2100	900	2300	940	1700	780	1800	690	1400	730	1400	570
Tin ug/g	ND	29	22	29	ND	ND	ND	ND	ND	210	ND	ND	ND	ND	ND	ND
Vanadium ug/g	33	26	34	28	32	21	35	19	30	17	26	12	25	19	24	11
Zinc ug/g	590	320	670	260	450	200	530	320	540	210	600	240	390	170	370	160

**Table B3: Road Deposited Sediment – PAH Chemistry**

Units		24-Aug-04				14-Sep-04				23-Sep-04			
		NBSW < 64	64-2000	NBUS < 64	64-2000	SBSW < 64	64-2000	SBUS < 64	64-2000	NBSW < 64	64-2000	NBUS < 64	64-2000
Fluorene	ug/g	<0.06	ND	<0.15	ND	0.06	0.04	0.03	ND	<0.30	ND	0.07	ND
Phenanthrene	ug/g	0.7	0.14	0.86	0.23	0.81	0.53	0.48	0.37	1.1	0.32	1.1	0.34
Anthracene	ug/g	<0.12	ND	<0.30	ND	0.09	0.07	ND	ND	<0.60	ND	<0.12	ND
Fluoranthene	ug/g	1.3	0.27	1.7	0.37	1.6	0.95	0.99	0.68	1.7	0.51	1.7	0.72
Pyrene	ug/g	1.2	0.19	1.4	0.28	0.96	0.53	0.57	0.41	1.5	0.4	1.1	0.41
Benz(a)anthracene	ug/g	0.34	0.06	0.48	0.09	0.43	0.27	0.25	0.2	0.68	0.17	0.47	0.24
Chrysene	ug/g	0.85	0.14	1.1	0.18	0.76	0.37	0.47	0.3	0.96	0.29	0.85	0.34
Benzo(b)fluoranthene	ug/g	0.91	0.12	1.1	0.13	0.91	0.35	0.43	0.26	0.82	0.27	0.79	0.35
Benzo(k)fluoranthene	ug/g	0.41	0.08	0.63	0.11	0.46	0.16	0.31	0.18	0.54	0.14	0.47	0.21
Benzo(a)pyrene	ug/g	0.5	0.08	0.66	0.11	0.52	0.29	0.34	0.24	0.65	0.2	0.56	0.29
Indeno(1,2,3-cd)pyrene	ug/g	0.65	0.1	0.85	0.11	0.53	0.25	0.33	0.23	0.67	0.21	0.6	0.26
Benzo(ghi)perylene	ug/g	0.79	0.09	1	0.13	0.53	0.27	0.37	0.21	0.83	0.25	0.82	0.29
Dibenz(ah)anthracene	ug/g	0.18	ND	0.23	ND	0.09	0.05	0.05	0.04	<0.40	0.05	0.1	0.04

Units		7-Oct-04				10-Nov-04			
		SBSW < 64	64-2000	SBUS < 64	64-2000	NBSW < 64	64-2000	NBUS < 64	64-2000
Fluorene	ug/g	0.08	0.33	0.04	ND	<0.30	0.04	<0.30	0.04
Phenanthrene	ug/g	1.5	4.5	0.66	0.36	0.99	0.54	1.2	0.59
Anthracene	ug/g	0.08	0.45	ND	ND	<0.60	ND	<0.60	ND
Fluoranthene	ug/g	3.7	7	1	0.51	1.3	0.79	1.8	0.87
Pyrene	ug/g	2	4.2	0.92	0.5	1.4	0.76	1.5	0.87
Benz(a)anthracene	ug/g	0.91	2	0.29	0.15	0.42	0.26	0.62	0.28
Chrysene	ug/g	1.5	2.6	0.57	0.27	0.8	0.38	1.1	0.4
Benzo(b)fluoranthene	ug/g	1.8	2.5	0.55	0.3	1.1	0.54	1	0.58
Benzo(k)fluoranthene	ug/g	1.1	1.9	0.48	0.1	<0.40	0.11	0.48	0.14
Benzo(a)pyrene	ug/g	1.1	2.3	0.39	0.19	0.55	0.31	0.7	0.33
Indeno(1,2,3-cd)pyrene	ug/g	1.2	1.9	0.35	0.14	<0.60	0.21	0.65	0.23
Benzo(ghi)perylene	ug/g	1.1	1.7	0.39	0.16	0.5	0.23	0.86	0.25
Dibenz(ah)anthracene	ug/g	0.27	0.35	0.05	ND	<0.40	ND	<0.40	0.05

**Table B3 (Continued): Road Deposited Sediment – PAH Chemistry**

Units		9-Aug-05								30-Aug-05							
		NBSW < 64	64-2000	NBUS < 64	64-2000	SBSW < 64	64-2000	SBUS < 64	64-2000	NBSW < 64	64-2000	NBUS < 64	64-2000	SBSW < 64	64-2000	SBUS < 64	64-2000
Fluorene	ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04
Phenanthrene	ug/g	0.28	0.21	0.43	0.12	0.53	0.38	0.69	0.26	0.79	0.56	0.4	0.14	0.47	0.42	1.1	0.42
Anthracene	ug/g	ND	ND	ND	ND	ND	0.07	0.06	0.03	0.08	0.06	ND	ND	ND	0.06	ND	0.05
Fluoranthene	ug/g	0.78	0.45	1.15	0.26	1.46	0.82	1.89	0.61	2.34	1.29	1.01	0.27	1.23	0.98	2.3	0.65
Pyrene	ug/g	0.76	0.39	1.06	0.23	1.22	0.7	1.5	0.48	1.93	1.03	0.9	0.22	1.11	0.81	2	0.53
Benz(a)anthracene	ug/g	0.27	0.2	0.4	0.11	0.4	0.33	0.56	0.22	0.8	0.43	0.55	0.1	0.5	0.36	0.8	0.25
Chrysene	ug/g	0.3	0.21	0.4	0.08	0.6	0.26	1.11	0.31	1	0.37	0.57	0.09	0.4	0.35	0.7	0.2
Benzo(b)fluoranthene	ug/g	0.73	0.28	0.85	0.17	1.3	0.52	1.35	0.35	2.1	0.85	0.7	0.18	0.97	0.66	1.7	0.41
Benzo(k)fluoranthene	ug/g	0.27	0.11	0.3	0.06	0.3	0.17	0.58	0.17	0.7	0.32	0.36	0.06	0.3	0.19	0.5	0.16
Benzo(a)pyrene	ug/g	0.33	0.16	0.39	0.09	0.58	0.32	0.74	0.22	1.06	0.53	0.36	0.1	0.47	0.4	0.8	0.26
Indeno(1,2,3-cd)pyrene	ug/g	0.3	0.2	0.3	ND	0.6	0.2	0.9	0.2	1.1	0.4	0.4	ND	0.4	0.3	0.7	0.2
Benzo(ghi)perylene	ug/g	0.4	0.2	0.4	ND	0.5	0.2	0.8	0.2	1.3	0.4	0.6	0.1	0.4	0.3	0.6	0.2
Dibenz(ah)anthracene	ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Units		4-Oct-05								27-Oct-05							
		NBSW < 64	64-2000	NBUS < 64	64-2000	SBSW < 64	64-2000	SBUS < 64	64-2000	NBSW < 64	64-2000	NBUS < 64	64-2000	SBSW < 64	64-2000	SBUS < 64	64-2000
Fluorene	ug/g	ND	ND	ND	ND	ND	ND	ND	0.06	0.1	ND	ND	ND	0.2	0.08	0.14	0.18
Phenanthrene	ug/g	0.6	0.27	0.52	0.14	0.52	0.24	1.21	0.81	1.6	0.65	1.6	0.42	2.9	1.26	2.33	1.61
Anthracene	ug/g	ND	ND	ND	ND	0.07	0.04	0.13	0.08	0.2	0.09	ND	0.08	0.3	0.13	0.21	0.28
Fluoranthene	ug/g	1.33	0.53	1.08	0.28	1.26	0.55	2.94	1.75	2.5	1.03	2.7	0.59	6.2	2.41	5.30	2.25
Pyrene	ug/g	1.24	0.46	1.06	0.26	1.19	0.47	2.37	1.4	2.2	0.83	2.3	0.49	5.1	1.9	4.30	1.77
Benz(a)anthracene	ug/g	0.56	0.2	0.47	0.13	0.56	0.25	0.99	0.65	0.9	0.4	1.2	0.21	2	0.7	1.6	0.7
Chrysene	ug/g	0.64	0.23	0.58	0.12	0.64	0.19	1.24	0.72	0.7	0.3	0.6	0.2	2.4	0.7	1.7	0.6
Benzo(b)fluoranthene	ug/g	0.97	0.3	0.73	0.16	0.97	0.33	1.91	1.03	1.5	0.51	1.6	0.26	4.3	1.3	3.25	1.01
Benzo(k)fluoranthene	ug/g	0.34	0.11	0.3	0.06	0.36	0.14	0.87	0.41	0.5	0.2	0.7	0.1	1.4	0.5	1.5	0.4
Benzo(a)pyrene	ug/g	0.45	0.16	0.36	0.09	0.54	0.22	1.09	0.68	0.8	0.3	1	0.19	2.5	0.87	2.12	0.75
Indeno(1,2,3-cd)pyrene	ug/g	0.5	0.2	0.4	ND	0.6	0.2	1.1	0.6	0.7	0.2	ND	ND	1.9	0.7	1.5	0.5
Benzo(ghi)perylene	ug/g	0.6	0.2	0.8	0.1	0.6	0.2	1.1	0.5	0.8	0.3	1	ND	1.9	0.7	1.8	0.6
Dibenz(ah)anthracene	ug/g	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND



# **APPENDIX C**

## **Simulated Runoff Chemistry**

### **List of Tables:**

**Table C1: Simulated Runoff - Nutrient chemistry**

**Table C2: Simulated Runoff – Total Metals chemistry**

**Table C3: Simulated Runoff – Dissolved Metals chemistry**

**Table C4: Simulated Runoff - PAH chemistry**

**Table C1: Simulated Runoff - Nutrient chemistry**

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Volume of Water	L			80	95	115	120	125	115	105	130
pH		7.8	7.7	7.8	7.6	7.9	7.8	7.8	7.8	8.0	7.7
Conductivity	uS/cm2	505	527	371	456	478	511	453	450	543	572
DO	mg/L	8.4	8.6	8.5	9.8	9.0	7.2	7.0	7.9	7.1	8.0
TOC (uv/persulf)	mg/L	34	38	27	16	37	49	33	35	13	19
TKN (as N)	mg/L	22	14	3.2	4.7	3.3	4.1	4.1	3.3	1.7	2
Total Phosphorus (as P)	mg/L	0.37	0.32	0.46	1.1	0.54	0.65	0.38	0.39	0.52	0.37
Chloride	mg/L					72	85				

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		SBSW	SBUS <sup>1</sup>	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Volume of Water	L			70	83	115	110	130	110	115	135
pH	-	7.8		7.9	7.9	7.7	7.8	7.8	7.9	7.8	7.9
Conductivity	uS/cm2	380		398	390	410	421	379	379	447	460
DO	mg/L	8.9		8.0	7.6	6.5	7.9	8.1	7.3	8.1	8.5
TOC (uv/persulf)	mg/L	39		39	31	42	39	37	36	15	13
TKN (as N)	mg/L	23		3.4	3	4.9	4.2	4.8	4.3	2	1.6
Total Phosphorus (as P)	mg/L	0.4		0.65	0.68	0.61	0.67	0.31	0.44	0.38	0.74
Chloride	mg/L					49	50				

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Volume of Water	L	135	125	130	135	110	125	130	115
pH		7.7	7.5	7.8	7.7	8.0	7.8	8.0	7.9
Conductivity	uS/cm2	490	568	373	386	386	461	354	367
DO	mg/L	8.1	7.4	8.7	8.3	8.7	8.2	9.7	10.0
TOC (uv/persulf)	mg/L	36.4	30.8	29.7	16.6	20.0	22.4	15.8	12.9
TKN (as N)	mg/L	2.9	2.2	5.3	5.5	5	4	7	7
Total Phosphorus (as P)	mg/L	0.81	0.49	2.86	1.01	1.19	0.55	1.50	1.04

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Volume of Water	L	90	130	125	140	130	120	120	110
pH		7.8	7.6	7.8	7.8	7.7	7.8	8.2	8.1
Conductivity	uS/cm2	390	429	344	358	356	371	337	350
DO	mg/L	7.3	7.4	8.9	8.6	7.7	8.1	9.8	9.9
TOC (uv/persulf)	mg/L	32.7	22.1	20.5	28.1	29.4	28	21.1	19.6
TKN (as N)	mg/L	2.8	2.6	4.5	5.8	4	7	11	12
Total Phosphorus (as P)	mg/L	0.95	0.81	1.56	1.93	0.67	1.4	3.67	3.52

**Table C2: Simulated Runoff – Total metals chemistry**

Table 07: Simulated Runoff - Total Metals Chemistry											
		24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
Units		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Aluminum	mg/L	3.7	3	3.1	2.8	7.4	5.6	4.1	3.1	12	5.6
Barium	mg/L	0.21	0.19	0.22	0.21	0.28	0.26	0.18	0.19	0.57	0.3
Boron	mg/L	0.1	0.11	0.057	0.072	0.093	0.12	0.15	0.16	0.065	0.054
Cadmium	mg/L	ND	ND	ND	0.007	ND	ND	ND	ND	ND	ND
Calcium	mg/L	120	110	120	130	170	150	110	110	390	180
Chromium	mg/L	0.028	0.026	0.033	0.031	0.047	0.038	0.034	0.03	0.12	0.048
Cobalt	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.014	ND
Copper	mg/L	0.089	0.1	0.12	0.13	0.14	0.13	0.19	0.15	0.39	0.17
Iron	mg/L	9.1	7.3	9.6	7.2	18	12	11	6.7	36	15
Lead	mg/L	0.035	0.051	0.038	0.05	0.062	0.047	0.056	0.038	0.19	0.086
Magnesium	mg/L	17	16	16	17	22	19	16	15	55	22
Manganese	mg/L	0.57	0.44	0.46	0.49	0.79	0.67	0.49	0.46	1.9	0.72
Molybdenum	mg/L	ND	ND	ND	ND	ND	ND	0.015	0.012	0.013	ND
Nickel	mg/L	0.018	0.018	0.018	0.018	0.027	0.021	0.017	0.018	0.043	0.015
Phosphorus	mg/L	0.39	0.38	0.43	0.95	0.78	0.73	0.59	0.51	1.6	0.65
Potassium	mg/L	5.1	5.1	4.4	6	5.6	5.9	4.6	4.6	4.5	4.1
Silicon	mg/L	6.7	5.2	5.6	4.9	12	9.1	7	5.2	13	7.6
Sodium	mg/L	55	64	33	46	41	49	36	39	29	33
Strontium	mg/L	0.48	0.45	0.38	0.42	0.49	0.47	0.35	0.36	0.78	0.45
Sulphur	mg/L	28	27	21	22	26	27	23	25	23	22
Tin	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Titanium	mg/L	0.18	0.14	0.16	0.13	0.34	0.24	0.19	0.13	0.54	0.25
Vanadium	mg/L	0.01	0.01	0.011	0.011	0.024	0.019	0.014	0.012	0.043	0.018
Zinc	mg/L	0.41	0.44	0.45	0.51	0.67	0.63	0.49	0.60	1.3	0.62
Zirconium	mg/L	ND	ND	ND	ND	0.013	ND	ND	ND	ND	ND

Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
	SBSW	SBUS <sup>1</sup>	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Aluminum	mg/L	7.8	5.8	7.2	6.2	8	2.9	4.3	7.5	9.9
Barium	mg/L	0.26	0.29	0.33	0.27	0.31	0.15	0.19	0.29	0.038
Beryllium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND
Boron	mg/L	0.12	0.11	0.09	0.13	0.13	0.18	0.18	0.051	0.051
Cadmium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	mg/L	170	170	190	160	180	91	110	220	320
Chromium	mg/L	0.04	0.047	0.051	0.039	0.042	0.02	0.025	0.05	0.066
Cobalt	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Copper	mg/L	0.11	0.14	0.15	0.12	0.12	0.074	0.082	0.15	0.21
Iron	mg/L	18	17	17	17	17	7.7	8.7	18	23
Lead	mg/L	0.05	0.069	0.07	0.049	0.057	0.025	0.033	0.076	0.12
Magnesium	mg/L	19	20	22	18	21	12	14	25	36
Manganese	mg/L	0.77	0.74	0.75	0.71	0.78	0.34	0.44	0.8	1.2
Molybdenum	mg/L	ND	0.014	0.011	0.011	ND	ND	ND	ND	ND
Nickel	mg/L	0.027	0.02	0.025	0.022	0.026	<	0.012	0.021	0.026
Phosphorus	mg/L	0.72	0.72	0.86	0.74	0.87	0.41	0.53	0.84	1.2
Potassium	mg/L	5.4	5.2	6	5.7	5.5	4.3	5.2	4.4	3.6
Silicon	mg/L	13	9.5	11	9.8	13	5.5	7.5	9.9	12
Silver	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sodium	mg/L	30	29	32	28	30	25	28	23	23
Strontium	mg/L	0.5	0.48	0.5	0.47	0.51	0.32	0.35	0.5	0.65
Sulphur	mg/L	25	26	23	26	26	23	24	20	20
Thallium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tin	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND
Titanium	mg/L	0.35	0.27	0.34	0.27	0.35	0.13	0.2	0.32	0.41
Vanadium	mg/L	0.02	0.019	0.021	0.018	0.022	0.01	0.013	0.023	0.03
Zinc	mg/L	0.46	0.48	0.54	0.51	0.55	0.28	0.35	0.5	0.68
Zirconium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND

**Table C2 (Continued): Simulated Runoff – Total metals chemistry**

Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Aluminum	3400	3500	14000	12000	11000	6300	16000	12000
Antimony	6.6	7.7	29	26	25	25	44	28
Arsenic	2.2	2.3	8.3	6.7	ND	4	8	5
Barium	150	180	560	480	580	420	740	510
Beryllium	ND	ND	1	0.8	ND	ND	1.1	0.9
Bismuth	ND	ND	1.3	ND	ND	ND	2	1
Boron	68	81	73	65	ND	60	81	64
Cadmium	0.7	0.9	3.6	2.4	3	1.8	3.0	2.2
Calcium	120000	110000	330000	240000	300000	190000	450000	340000
Chromium	38	33	160	110	120	75	140	97
Cobalt	4.1	3.4	17	13	17	8	20	12
Copper	110	110	400	330	360	250	460	350
Iron	14000	86000	63000	37000	65000	22000	60000	32000
Lead	47	48	230	190	160	110	220	160
Lithium	8.7	14	28	22	ND	10	25	17
Magnesium	21000	19000	51000	41000	46000	30000	65000	53000
Manganese	540	450	2600	2000	2100	1200	2400	1800
Molybdenum	7.5	7.3	16	15	15	13	23	16
Nickel	14	27	56	45	43	27	56	36
Phosphorus	0.81	0.49	2.86	1.01	1.19	0.55	1.50	1.04
Potassium	3800	4400	7100	7000	5000	4900	6400	5500
Selenium	ND	ND	2.3	ND	ND	ND	ND	ND
Silicon	6300	6100	24000	22000	20000	11000	28000	20000
Silver	ND	ND	0.6	ND	ND	ND	ND	ND
Sodium	43000	47000	29000	37000	32000	47000	28000	33000
Strontium	410	340	690	600	720	550	770	650
Tellurium	ND	ND	ND	ND	ND	ND	ND	ND
Thallium	0.08	0.06	0.21	0.21	ND	0.11	0.29	0.21
Thorium	2.6	1.8	8	5.8	ND	3	8	5
Tin	4	3.7	17	14	14	13	19	12
Titanium	230	270	890	780	800	470	1100	730
Tungsten	7.7	2	30	7.1	45	4	28	3
Uranium	0.6	0.5	1.4	1.1	1	0.8	1.6	1.2
Vanadium	15	14	60	48	34	29	63	43
Zinc	570	600	2200	1800	1800	1300	2200	1600
Zirconium	4.2	4.2	12	14	14	11	22	15

Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Aluminum	5800	6800	9900	13000	5300	10000	47000	35000
Antimony	9	9.6	16	20	12	23	45	53
Arsenic	3.1	3.4	4.8	5.7	3	5	19	16
Barium	210	230	340	450	340	520	1500	1400
Beryllium	ND	ND	0.8	0.6	0.5	0.5	3	2
Bismuth	ND	ND	ND	ND	ND	1	2	2
Boron	78	68	56	68	73	74	110	100
Cadmium	1.1	1	2	2.2	1.7	1.7	6.0	3.6
Calcium	150000	170000	190000	230000	210000	220000	1200000	1000000
Chromium	44	45	75	82	51	93	310	250
Cobalt	5.6	5.6	9.7	11	8.6	10	47	35
Copper	110	120	200	250	210	240	750	690
Iron	20000	16000	35000	33000	25000	29000	150000	94000
Lead	58	59	98	120	91	120	440	350
Lithium	19	18	20	22	9	18	59	54
Magnesium	21000	23000	37000	31000	28000	33000	120000	120000
Manganese	610	680	1100	1400	1000	1200	5300	4400
Molybdenum	9.9	8.5	11	15	17	24	38	36
Nickel	17	19	30	35	21	34	120	99
Phosphorus	0.95	0.81	1.56	1.93	0.67	1.4	3.67	3.52
Potassium	4000	4500	4800	6200	3800	5500	11000	10000
Selenium	ND	ND	ND	ND	ND	ND	ND	ND
Silicon	10000	11000	17000	21000	8400	19000	65000	54000
Silver	0.5	ND	ND	ND	ND	0.8	2	ND
Sodium	25000	26000	19000	28000	21000	25000	24000	26000
Strontium	410	440	480	570	580	540	1900	1700
Tellurium	ND	ND	ND	ND	ND	ND	ND	ND
Thallium	0.1	0.12	0.14	0.18	0.07	0.17	0.7	0.6
Thorium	2.8	3	4.4	4.7	2	5	23	16
Tin	4.9	4.5	7.7	8.6	6	15	28	28
Titanium	370	410	590	690	270	720	2800	2200
Tungsten	14	3.3	17	6.5	12	5	51	8
Uranium	0.6	0.6	0.7	1	0.6	0.9	3.6	3.0
Vanadium	19	20	32	37	22	39	150	130
Zinc	560	560	1100	1300	1100	1200	3500	3000
Zirconium	6.6	6.6	8.6	11	7	13	53	45

**Table C3: Simulated Runoff – Dissolved metals chemistry**

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Aluminum	mg/L	ND	ND	ND	0.056	ND	ND	ND	ND	ND	ND
Barium	mg/L	0.11	0.097	0.086	0.13	0.11	0.13	0.079	0.088	0.082	0.079
Boron	mg/L	0.1	0.11	0.064	0.066	0.092	0.11	0.15	0.16	0.062	0.06
Cadmium	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	mg/L	65	66	59	88	69	71	59	59	54	58
Chromium	mg/L	0.006	0.007	0.007	0.007	0.005	0.005	0.007	0.008	0.006	0.007
Cobalt	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	mg/L	0.021	0.039	0.031	0.011	0.027	0.031	0.07	0.051	0.014	0.021
Iron	mg/L	0.64	0.011	ND	1.4	0.015	0.059	0.07	0.019	0.023	0.025
Lead	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium	mg/L	9.8	9.5	8.5	9	10	9.8	9.3	9.3	8.7	8.7
Manganese	mg/L	0.32	0.05	0.005	0.31	0.048	0.25	0.11	0.028	0.15	0.051
Molybdenum	mg/L	ND	ND	ND	ND	ND	ND	0.013	ND	ND	ND
Nickel	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phosphorus	mg/L	ND	ND	ND	0.072	ND	ND	ND	ND	ND	ND
Potassium	mg/L	4.4	4.7	4	4.9	3.6	5.1	3.8	4.1	2.9	3.8
Silicon	mg/L	1.3	0.83	0.68	1	1.2	1.2	1	0.96	1.3	0.91
Sodium	mg/L	54	61	31	44	43	50	40	41	29	34
Strontium	mg/L	0.39	0.37	0.27	0.34	0.35	0.36	0.29	0.29	0.27	0.27
Sulphur	mg/L	28	27	21	22	26	27	24	25	19	21
Zinc	mg/L	0.079	0.1	0.072	0.22	0.066	0.12	0.098	0.1	0.004	0.051

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		SBSW	SBUS <sup>1</sup>	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Aluminum	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Barium	mg/L	0.089		0.11	0.1	0.12	0.12	0.082	0.089	0.069	0.073
Boron	mg/L	0.12		0.11	0.087	0.13	0.12	0.17	0.19	0.05	0.042
Cadmium	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Calcium	mg/L	62		69	64	68	71	56	59	54	51
Chromium	mg/L	0.005		ND	0.009	0.0006	0.006	0.005	0.009	0.004	0.006
Cobalt	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Copper	mg/L	0.019		0.023	0.026	0.016	0.028	0.009	0.03	0.015	0.013
Iron	mg/L	0.29		0.082	ND	0.62	0.011	0.52	0.013	ND	ND
Lead	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Magnesium	mg/L	8.2		8.5	8.3	8.7	9.1	8.2	8.5	8.2	8.2
Manganese	mg/L	0.31		0.27	0.049	0.31	0.054	0.17	0.031	0.033	0.015
Molybdenum	mg/L	ND		ND	ND	ND	ND	0.012	0.012	ND	ND
Nickel	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Phosphorus	mg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Potassium	mg/L	3.7		4.2	4.3	4.8	4.8	3.8	4.3	3.2	2.7
Silicon	mg/L	1.2		1.2	1.1	1.1	1.2	1.1	1.2	1.1	1.2
Sodium	mg/L	30		28	31	28	30	25	29	23	24
Strontium	mg/L	0.32		0.31	0.29	0.33	0.33	0.26	0.27	0.25	0.24
Sulphur	mg/L	25		26	23	25	25	23	23	19	18
Zinc	mg/L	0.04		0.046	0.039	0.058	0.049	0.046	0.044	0.024	0.021

**Table C3 (Continued): Simulated Runoff – Dissolved metals chemistry**

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Aluminum	µg/L	28	25	17	16	26	18	22	23
Antimony	µg/L	1.3	1.5	1.8	1.4	2	2	2	2
Barium	µg/L	46	50	59	52	84	96	73	73
Boron	µg/L	77	74	57	45	50	53	51	44
Cadmium	µg/L	0.1	0.1	ND	0.1	ND	0.2	ND	ND
Calcium	µg/L	51000	49000	53000	53000	60000	58000	55000	53000
Chromium	µg/L	ND	ND	ND	ND	ND	7	ND	ND
Cobalt	µg/L	ND	ND	0.8	ND	ND	ND	ND	ND
Copper	µg/L	22	23	24	23	13	21	10	11
Iron	µg/L	51	ND	ND	ND	ND	ND	ND	ND
Lead	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Lithium	µg/L	6.9	6.1	5.3	ND	6	6	ND	ND
Magnesium	µg/L	9300	8800	9000	8800	9200	8500	9500	9100
Manganese	µg/L	48	13	320	3.7	14	15	83	12
Molybdenum	µg/L	4.1	3.9	3.9	2.7	4	4	4	4
Nickel	µg/L	2.4	3.2	2.5	2.3	3	3	2	1
Phosphorus	µg/L	54	ND	ND	ND	ND	ND	ND	ND
Potassium	µg/L	3000	34000	3900	3200	3000	3700	3000	2900
Silicon	µg/L	590	630	830	820	820	740	970	920
Sodium	µg/L	41000	46000	31000	29000	31000	47000	30000	31000
Strontium	µg/L	310	270	270	250	280	280	260	250
Uranium	µg/L	ND	0.2	ND	ND	ND	ND	0.3	0.3
Vanadium	µg/L	ND	2.4	ND	1.2	ND	2	ND	ND
Zinc	µg/L	66	72	29	85	26	110	34	39

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Aluminum	µg/L	23	23	25	18	19	18	34	19
Antimony	µg/L	1.4	1.4	1.4	2.2	2	2	3	3
Barium	µg/L	51	51	55	66	110	110	78	80
Boron	µg/L	76	68	49	63	70	59	43	40
Cadmium	µg/L	0.1	0.1	0.1	0.1	0.1	0.1	ND	ND
Calcium	µg/L	50000	55000	50000	56000	64000	64000	58000	54000
Chromium	µg/L	ND	ND	ND	ND	ND	5	ND	ND
Cobalt	µg/L	ND	ND	ND	ND	1.1	ND	ND	ND
Copper	µg/L	19	21	17	25	17	21	9	11
Iron	µg/L	ND	51	ND	ND	ND	ND	ND	ND
Lead	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Lithium	µg/L	8.6	6.4	5.1	7.3	8	6	ND	ND
Magnesium	µg/L	8000	8400	8300	8200	8600	8700	9500	8900
Manganese	µg/L	31	9.2	120	41	230	21	83	23
Molybdenum	µg/L	3.7	3.2	3.2	4.8	14	14	5	4
Nickel	µg/L	2.7	ND	1.6	2.2	4	3	1	2
Phosphorus	µg/L	ND	ND	ND	ND	ND	ND		
Potassium	µg/L	2600	2800	2500	3200	3200	3500	3100	3000
Silicon	µg/L	700	690	730	810	860	890	1500	1300
Sodium	µg/L	24000	27000	19000	26000	22000	26000	23000	26000
Strontium	µg/L	270	300	240	250	280	270	290	260
Uranium	µg/L	ND	0.2	ND	ND	ND	ND	0.3	0.3
Vanadium	µg/L	1.1	ND	ND	ND	ND	1	ND	ND
Zinc	µg/L	30	42	20	56	4	77	12	20

**Table C4: Simulated Runoff - PAH chemistry**

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Naphthalene	µg/L	ND	ND	ND	ND	0.1	0.32	ND	ND	0.5	0.3
2-Methylnaphthalene	µg/L	ND	ND	ND	ND	N/A	N/A	ND	ND	ND	ND
1-Methylnaphthalene	µg/L	ND	ND	ND	ND	N/A	N/A	ND	ND	ND	ND
Acenaphthylene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthene	µg/L	ND	ND	ND	ND	0.05	0.081	ND	ND	ND	ND
Fluorene	µg/L	ND	ND	ND	ND	0.068	0.11	ND	ND	0.5	ND
Phenanthrene	µg/L	0.5	0.3	0.3	0.5	0.91	1.5	1.1	0.7	5	1.3
Anthracene	µg/L	0.5	ND	ND	ND	0.081	0.15	ND	ND	0.5	ND
Fluoranthene	µg/L	0.9	0.5	0.5	0.9	1.3	2	1.7	0.7	8.4	2
Pyrene	µg/L	0.7	0.4	0.5	0.6	1.1	1.6	2.5	1	5.9	1.4
Benzo(a)anthracene	µg/L	0.2	ND	ND	0.3	0.37	0.54	0.7	ND	2	0.4
Chrysene	µg/L	0.6	0.3	0.4	0.5	0.59	0.79	1.2	<0.4	3.9	1
Benzo(b)fluoranthene	µg/L	0.5	ND	ND	0.5	0.68	0.89	ND	ND	3.7	0.8
Benzo(k)fluoranthene	µg/L	ND	ND	ND	ND	0.24	0.33	ND	ND	2.2	0.6
Benzo(a)pyrene	µg/L	ND	ND	ND	ND	0.43	0.6	ND	ND	2.3	0.5
Indeno(1,2,3-cd)pyrene	µg/L	ND	ND	ND	ND	0.34	0.45	ND	ND	2.2	0.6
Benzo(ghi)perylene	µg/L	0.5	ND	ND	0.4	0.43	0.61	ND	ND	3.0	0.9
Dibenz(ah)anthracene	µg/L	ND	ND	ND	ND	<0.076	<0.11	ND	ND	0.6	ND

	Units	24-Aug-04		14-Sep-04		23-Sep-04		7-Oct-04		10-Nov-04	
		SBSW	SBUS <sup>1</sup>	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Naphthalene	µg/L	ND		ND	ND	0.46	0.5	ND	ND	ND	ND
2-Methylnaphthalene	µg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene	µg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene	µg/L	ND		ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthene	µg/L	ND		ND	ND	0.061	0.046	ND	ND	ND	ND
Fluorene	µg/L	ND		ND	ND	0.14	0.077	ND	ND	ND	ND
Phenanthrene	µg/L	0.9		1.8	1.4	2.1	1.2	0.5	0.5	2	2.7
anthracene	µg/L	ND		ND	ND	0.18	0.097	ND	ND	ND	ND
Fluoranthene	µg/L	1.4		2.6	2.4	3.8	2.1	0.7	0.5	3.5	4.8
Pyrene	µg/L	1.1		1.9	1.8	2.8	1.7	1	0.9	2.3	3.1
Benzo(a)anthracene	µg/L	0.4		0.9	0.7	0.65	0.42	ND	ND	0.7	1.1
Chrysene	µg/L	0.8		1.3	1.3	1.1	0.91	<0.6	ND	1.7	2.2
Benzo(b)fluoranthene	µg/L	0.8		1.2	1	1.9	1.1	ND	ND	1.6	2.1
Benzo(k)fluoranthene	µg/L	0.5		0.8	0.8	0.54	0.32	ND	ND	1.1	1.5
Benzo(a)pyrene	µg/L	ND		0.8	0.8	1.2	0.71	ND	ND	0.9	1.1
Indeno(1,2,3-cd)pyrene	µg/L	ND		0.6	0.7	1.2	0.63	ND	ND	1	1.4
Benzo(ghi)perylene	µg/L	0.7		0.7	0.8	1.2	0.8	ND	ND	1.3	1.7
Dibenz(ah)anthracene	µg/L	ND		ND	ND	<0.25	0.12	ND	ND	ND	ND

**Table C4 (Continued): Simulated Runoff - PAH chemistry**

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Naphthalene	µg/L	ND	0.05	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylnaphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene	µg/L	0.9	0.33	1.6	0.8	2	1	5	ND
Anthracene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene	µg/L	2.1	0.64	4.1	1.5	4.4	2	8	7
Pyrene	µg/L	1.9	0.56	3.4	1.3	3.9	1.9	7	6
Benz(a)anthracene	µg/L	ND	0.19	1.4	0.9	1.7	1	ND	ND
Chrysene	µg/L	0.8	0.28	1.6	0.6	1.6	0.8	ND	ND
Benzo(b)fluoranthene	µg/L	1.1	0.44	2.9	1	3.3	1.5	ND	ND
Benzo(k)fluoranthene	µg/L	0.5	0.11	1	ND	1.1	ND	ND	ND
Benzo(a)pyrene	µg/L	0.5	0.21	1.2	0.4	1.7	0.7	3	2
Indeno(1,2,3-cd)pyrene	µg/L	ND	0.3	1	ND	1	ND	ND	ND
Benzo(ghi)perylene	µg/L	1	0.4	1	ND	2	1	ND	ND
Dibenz(ah)anthracene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND

	Units	9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Naphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylnaphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene	µg/L	0.9	1.1	0.7	2.7	2.3	2.9	14	19
Anthracene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene	µg/L	2.4	2.4	1.6	2.7	5	6.8	29	41
Pyrene	µg/L	1.9	1.8	1.3	2.4	4.2	5.7	23	33
Benz(a)anthracene	µg/L	2.5	0.7	0.9	0.9	2	2.2	10	15
Chrysene	µg/L	0.9	1.1	0.7	1	2.5	2	11	15
Benzo(b)fluoranthene	µg/L	1.5	1.6	1.2	1.9	3.9	5.2	17	23
Benzo(k)fluoranthene	µg/L	0.5	0.5	ND	0.6	1	1.5	7	10
Benzo(a)pyrene	µg/L	0.6	0.73	0.5	0.8	2	2.2	10	15
Indeno(1,2,3-cd)pyrene	µg/L	1	1	ND	ND	2	2	ND	12
Benzo(ghi)perylene	µg/L	1	1	ND	ND	2	3	ND	12
Dibenz(ah)anthracene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND



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