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**EFFECTIVENESS OF STREET
SWEEPING IN STORMWATER
POLLUTION SOURCE CONTROL**

Final Report

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V. Stevanovic-Briatico and S. Kok**

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Effectiveness of Street Sweeping in Stormwater Pollution Source Control

Final Report

A Summary of the 2004, 2005 & 2006 Field Seasons, Markham Road, Toronto

AEMRD-TN07-006



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ABSTRACT

The effectiveness of street sweeping as a pollution source control measure aimed at 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 (13,000 vehicles / day in each direction). 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 m²) and dry samples were collected using an industrial vacuum cleaner over a similar 80 m² area. A total of 30 pairs (swept / unswept) of wet samples and 25 pairs of dry samples were collected during the field season between 2004 and 2006. 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 or negative improvement. Analysis of the data collected 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 the runoff (e.g., Zn). Such benefits may be offset by increased capital costs of sweeping with this type of high-efficiency PM₁₀ sweeper.

RESUME

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). Nous avons 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 (13,000 véhicules/jour en chaque direction). Nous avons 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. Nous avons prélevé des échantillons immédiatement après le passage de la balayeuse. Nous avons obtenu des échantillons humides en lavant une section de 20 m de la voie en bordure (80 m²) et nous avons recueilli des échantillons secs en utilisant un aspirateur industriel sur une section similaire de 80 m². Nous avons recueilli en tout 30 paires (parcelles balayées / parcelles non balayées) d'échantillons humides et 25 paires d'échantillons secs au cours des saisons entre 2004 et 2006. Nous avons évalué les différences entre les 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 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 PM₁₀.

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1 INTRODUCTION

1.1 Street Sweeping as a Method of Stormwater Source Control

Over the last 160 years, street sweeping has evolved considerably. Originally, sweepers were developed to collect horse manure and litter and increase the safety of people and vehicles on city streets by removing debris from the road surfaces. Initially, the role of the street sweeper was mainly one of aesthetics, but this was later expanded to include the management of road deposited sediment. These solids could accumulate in drainage paths, block catchbasins and clog sewer pipes. In the USA, the first street sweeper was patented by C.S. Bishop in 1849 (Patent number 6,699). This horse-drawn mechanical sweeper utilized brooms and scrapers (driven by the rotation of the cart wheels) and gutter brushes to load street debris onto a conveyor which dropped into a hopper. The principle of operation of the modern-day conventional mechanical (broom) sweeper has remained quite similar to the original machine, with advances in the areas of mechanical improvements (rotating gutter brooms and larger main brooms) and some dust suppression techniques. New developments with sweeping technologies have applied vacuum systems to the older technology in an effort to remove finer particles from the road surface. Stronger vacuums, better filtration of air, dust control and the use of air currents (in regenerative air sweepers) have seen major improvements in road cleaning ability.

1.1.1 Early research in street sweeping

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 stormwater quality improvement by street sweeping is not generally supported by the collected field data, even though it could occur in isolated, site specific cases (USEPA, 1983).

Sartor and Gaboury (1984) performed a study in California during the NURP era and used conventional mechanical (broom) sweepers. They determined that most of the pollutants were in sediments $< 250 \mu\text{m}$ (e.g., 62% of the total Pb contamination was accounted for by 42% of the total weight of particles). They found that the conventional

sweepers tested were somewhat ineffective for pollution control as they did not target these smaller particles. They recommended that sweeper performance would be best assessed by changes in the end-of-pipe stormwater runoff concentrations rather than by an analysis of material collected in the street sweeper hoppers. From these results, the greatest influence on street sweeping effectiveness appeared to be the time intervals between sweeping. It was found that the greatest improvements to water quality could be achieved if sweeping occurred within the storm inter-event period. The total mass of sediment on the road (available to be removed), the efficiency of the sweeper, the rate at which pollutants accumulate and the partitioning of the material to various particle sizes were also important in determining the effectiveness of street sweeping. They determined removal rates of up to 30% were possible for road sediments, total suspended solids (TSS) in runoff could be reduced by 30-40% and metals such as Pb could be reduced by up to 80%. The researchers suggested that the increased concentrations of pollutants in the runoff, which often accompanied the swept catchments, could be explained by the abrasion and degradation action of the sweeper brooms on the road surface. This action could break down the larger particles, which would make them more susceptible to washoff and transport, particularly by less-intense storms which may lack the power to wash off the larger solids.

Bender and Terstriep (1984) also studied the effectiveness of street sweeping, during the NURP era evaluations. Four drainage basins in Champaign, Illinois (ranging from 6.5-22.3 ha in size) were used to test the effectiveness of conventional mechanical (broom) sweepers. Ninety storm events were analysed covering periods of both active sweeping (at various frequencies) and periods with no sweeping. The event mean concentrations (EMCs) were calculated for the collected runoff samples and it was found that they were log normally distributed. Street loadings (as assessed by sweeper contents) were found to be highly variable (20 to 300 kg/curb km). While significant reductions were noted for some constituents (TSS up to 40%, Pb up to 48%, Fe up to 60%, COD up to 35%) but not others (TP and TKN), in some of the test catchments, other catchments displayed no difference. The study concluded that street dirt loads could be reduced by mechanical sweepers, but even if swept twice weekly, the quality of runoff was not significantly affected.

1.1.2 Models predict improved water quality as a result of street sweeping

Stormwater pollution has been modelled 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 can also contribute to stormwater pollution. The mechanism of pollutant accumulation and washoff suggests that if such accumulations can be 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. Some examples of more recent research follows.

The negative assessment of street sweeping, which was based mainly on the earlier NURP work, prevailed until 1997, when new information on street sweeping was published by Sutherland and Jelen (1997 and 1998). They 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, total Cu, Pb and Zn, and TP by 20-60% in the runoff. 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 are unable to retain such soluble contaminants, hence street sweeping could be an effective way to deal with soluble contaminants in stormwater.

Sutherland et al., (1998) evaluated street sweeping in the port of Seattle, when they conducted a survey of proposed stormwater treatment Best Management Practices (BMPs) for a new container yard. Wet vaults were initially considered to be the only suitable technology for the site. As an alternative, computer models were used to predict the impact of street sweeping in combination with regular catchbasin cleaning. Model results suggested that weekly high-efficiency sweeping combined with annual catchbasin cleaning could provide the same level of treatment without costly excavation and construction. The simulations further showed that sweeping twice per month was not effective enough and increasing the frequency above once per week did not significantly improve the removal of selected contaminants.

Zarriello et al., (2002) incorporated street sweeping into the new model being used to predict the effects of BMPs on receiving water quality. This study evaluated the potential for reducing stormwater loadings of TSS, fecal coliform, total Pb and TP using both structural (settling, infiltration, bioretention) and non-structural BMPs (street sweeping). Street sweeping was considered to be a good option due to limitations in space in congested downtown areas, which would make installation of ponds or wetlands impossible. A USGS model used for the Lower Charles watershed was modified to simulate the effects of sweeping. Structural BMPs could have wide variations in performance, so average values were used in the model. Estimates for the accretion and erosion of pollutants, washoff during rain or snowmelt events, and typical sweeper efficiencies were also used and then compared against annual loads obtained from storm runoff data to calibrate the model. Street sweeping less often than once per week had little to no impact on runoff quality simulations. Sweeping more often than once per week showed more positive results; reductions for TSS (76%), fecal coliform (72%) and TP (72%) were calculated. The washoff value (which controls the removal of built-up pollutants during storms) used in the model was critical to the effectiveness calculations and needed to be adjusted carefully. The reduction of pollutants with both routine street sweeping and structural BMPs factored in were 44% for TSS, 7.5% for fecal coliforms, 11% for total Pb and 4.9% for TP. They concluded that these estimates were subject to further modifications once field measurements were used to confirm model results and that highly variable removal rates were to be expected.

1.1.3 Testing of high-efficiency sweepers

Street sweepers which incorporated new vacuum technology gradually became more prevalent. These sweepers targeted the finer particles which conventional mechanical sweepers could not pick up. They also incorporated filters to reduce the dust generated by sweeping. A number of researchers felt that the time had come to re-examine the street sweeping issue, as the new high-efficiency vacuum sweepers held the promise of greatly improved fine sediment removal. As the fine sediments were generally more contaminated, their removal should also lead to receiving water quality improvement.

Effectiveness of street sweepers on removing metals from streets was assessed in a study in Sweden, by German and Svensson (2002). Samples were collected by industrial vacuum over 20 m² test areas before and after sweeping. It was found that the highest concentrations of heavy metals were in the finest grain sized sediment. The sweeper could remove particles of all sizes during sweeping, but if sediment loadings were low before sweeping, the sweeper often appeared to "generate" some additional solids (the researchers thought these solids may be a result of abrasion of the road surface or breakdown of existing particles). The greatest loading of metals were found in the sand fractions ($64\text{ }\mu\text{m} < d < 125\text{ }\mu\text{m}$), which were not well-transported during storm events, but could be easily swept by vacuum sweepers or retained by sedimentation ponds. If these same sediments were left on the street, however, the attached metals may be more easily washed off (e.g., during acid rain) or the particles may be more easily transported during wind or storm events.

An Australian report by Taylor and Wong (2002a) assessed the values of non-structural BMPs in protecting water quality. They found that non-structural BMPs (including street sweeping and other source control measures) were already in use in Australia and were contributing to improvements in urban stormwater quality. Their use was steadily increasing and would continue to do so if the Australian programmes are developed in the same way as other countries. Monitoring and evaluation of non-structural BMPs was considered to be very important in order to guide future programmes. The companion report by Taylor and Wong (2002b) calculated the performance of various non-structural BMPs, including street sweeping. For street sweeping they suggested that 50% total solids removal was possible with mechanical broom sweepers (15% for $< 43\text{ }\mu\text{m}$ particles), which corresponded to reductions in metals (47%), phosphate (26%), nitrate (36%) and BOD (44%). They also summarized 5 studies of runoff concentrations which showed some reductions in TSS (41%), Pb, Zn, Cu, Cd, Fe (32 – 45%), TP (28%), SP (45%), organic nitrogen (ON) (27%), COD (35%) and litter (98%).

Waschbusch (2003) used a paired basins experiment in Milwaukee, Wisconsin, to evaluate the effect of street sweeping on runoff quality. They used 24 single pulls of a vacuum wand at each location to sample the hard shoulder of a highway test area and automatic sampling of runoff. Many problems appeared to arise during this study, including the presence of local road construction, which likely skewed test data. Large particles in sediment samples made splitting samples difficult and further skewed particle size distributions. Total suspended solids data were also difficult to analyze due to a bias

towards lighter/smaller particles and therefore suspended sediment analyses were preferred. Poor sweeper performance was noted on a number of occasions, which was attributed to equipment malfunctions, poor pavement conditions, type of street dirt being picked up (gravel or fines), location of solids or composition. The benefits of sweeping were hard to demonstrate due to the very high level of variability experienced with the data.

Breault et al., (2005) studied the relative efficiencies of currently-available technologies for conventional mechanical (broom type) and vacuum sweepers. During this study, street dirt accumulation rates ranged from 2.1 to 41 g/curb m/d (average 14 g/curb m/d) and 56% of this material was coarse sand. The highest contamination by trace metals was found in the fine sediments ($< 63 \mu\text{m}$), however the greatest contribution of metal mass was from the coarse-grained material (approximately 30%). The larger particles also accounted for 27% of the total PAH loadings. Ratios of PAH compounds (anthracene:anthracene + phenanthrene = 0.16, phenanthrene:anthracene = 0.71, fluoranthene:pyrene = 0.80) found in this study indicated similar ratios to other sites contaminated by degraded asphalt and motor oil. Sweeper efficiencies were assessed using a pre-cleaned sweeper (including conveyors and all broom/brush systems), applying a known amount of dirt (of known particle size distribution) to the pre-cleaned street and operating the sweepers as would normally be done. This was laid down at about 36 g/curb m in a 1 m wide swath along the curb. The conventional mechanical street sweeper demonstrated efficiencies between 20% and 31% and the vacuum sweeper was able to achieve between 60% and 92% efficiency. The vacuum sweeper was found to be 1.5 to 5 times more efficient at picking up particles in the 2000 to $250 \mu\text{m}$ particle size range. Results from this study were incorporated into computer models which simulated the effectiveness of structural and non-structural BMPs in the protection of receiving water quality.

1.1.4 Street sweeping research by municipalities

Street sweeping has been investigated by a number of researchers in conjunction with municipalities to examine new options, products or better methods to control road deposited sediment. Most of the study results have been highly variable, with few consistently significant removals noted. Many municipalities and consultants have therefore developed guidelines based on their experiences in street sweeping programmes which help to make sweeping more effective.

Early research by Walton (1988) in Newark, New Jersey, suggested that due to variations in local conditions, it would be best to test all of the sweepers being considered before purchase. In this case, sweepers had to clean a "standard" litter-strewn street. Other municipalities may choose different materials depending on their requirements or goals. As part of the renewed interest in street sweeping, parking enforcement fines were also increased, which provided some revenue (to help offset the cost of the new equipment) and ensured a more complete clean up of the streets.

In an effort to save the salmon fishery which was suffering notable reductions due to high levels of urban pollution in the Pacific Northwest, Minton et al., (1998) proposed the use of high-efficiency street sweeping as a source control measure. Their research promoted the use of (in this case) a Schwarze Industries EV series machine, which could sweep dry (without water sprays) and use 2.9 μm filters to clean the air ($> 70\%$ efficiency for $< 64 \mu\text{m}$). In their tests, sampling of unswept material was performed first, the sweeper was then used to sweep the test section and the residual was examined afterwards. The researchers noted that if loadings were $< 32 \text{ kg/curb km}$, NURP era sweepers would not be able to demonstrate any removal, however, the new EnviroWhirl machines were able to reduce down to about 3 kg/curb km . Minton et al., (1998) also challenged the conclusions arising from the NURP study which used a paired catchment design with end-of-pipe monitoring. The results from the NURP study showed reductions in 60% of cases, but since the USEPA established that $> 50\%$ removal was required for the result to be significant, most of the data were not considered to be significant. Increases were found for 32% of cases and 8% of cases showed no change. Minton et al., (1998) argued that the rainfall intensity variation was likely to influence the results, but was not considered in the original studies. The conventional mechanical sweepers used during this study were found to leave behind particles $< 250 \mu\text{m}$, which contain a great majority of pollutants. They also proposed that these sweepers removed the litter and surface dirt, leaving the smaller particles unprotected and thus more likely to be washed off in a storm event, which contributed to the observed increases in effluent water quality parameters.

Kuennen (2001) reported that significant progress in dust control technology allowed El Paso Texas to be ranked highest in USA for reducing PM_{10} and $\text{PM}_{2.5}$ levels in the city. They used a fleet of 20, PM_{10} certified, Elgin Eagle (high-efficiency mechanical) sweepers 6 days per week in downtown (4 times per year in residential areas), to cover the 3000 paved kilometres downtown. Over 25,000 tonnes of debris were dumped annually into a series of roll-off dumpsters strategically placed around the city. This efficiency has allowed the fleet to maintain active sweeping for longer periods, rather than transporting the sweepers to and from worksites.

Tobin and Brinkman (2002) investigated the use of both broom and vacuum type sweepers under the highly sandy conditions in Florida. It was found that broom sweepers were more effective on the asphalt roadways in this area and removed total sediment loads as well as Al, Cd, Cu, Pb, P, volatile solids, organic matter (of which there was a considerable amount in this study), TKN, NH_3 , NO_3^- , NO_2^- and oil & grease. Vacuum sweepers were found to be more efficient at removing P and COD. This was in strong contrast to the majority of other studies which suggested that the more expensive vacuum sweepers would be more suitable. In this case, the specific conditions of the sites tested would warrant the use of broom sweepers. Site evaluation and field testing would be well-advised before sweepers are purchased.

Pitt and Clark, (2003) summarized the effectiveness of a multitude of stormwater BMPs and management options, including the use of street sweepers. They found that streets were generally made cleaner after rainfall events than the threshold level of effectiveness of most sweepers tested, therefore sweeping immediately after rain events would have

limited (if any) effect. The particles left behind after sweeping also appeared to be more susceptible to washoff than unswept particles; this supports the argument that sweeping could result in an increase in pollutant levels in urban runoff. They noted that few studies were able to demonstrate consistent (and significant) removal rates for sweepers, but with good sweeping practices, it should be possible to have a positive effect under certain conditions. Although somewhat less effective, manual sweeping (e.g., in New York City) may even be able to provide improved runoff quality. For pollutant removal effectiveness, it was found to be most important that sweepers were able to remove the finest particle sizes from the road surface. Tandem operations (conventional mechanical sweeper, followed by a vacuum sweeper or a regenerative air sweeper) showed the greatest promise of improved runoff quality.

The city of Roseville, Michigan took proactive measures to improve both air quality and water quality (as part of the NPDES phase II), using street sweeping (City of Roseville, 2005). The ability to sweep the streets in winter without water extended the season and increased the amount of solids (and salt) removed from the roads, which helped to improve the runoff quality and protected the receiving waters. The replacement of older conventional mechanical equipment allowed for an increased sweeping efficiency and a greater number of options, including dustless and waterless sweeping.

The implementation of both structural and non-structural BMPs is one of the requirements of the USEPA stormwater runoff permit program. Muhammad and Hooke (2006) investigated different source control strategies in Oxford, Ohio, including street sweeping. They noted that a number of much earlier studies (during the NURP era) had found poor removal of fines but they were encouraged that several recent studies had shown that some high-efficiency sweepers were capable of reducing pollutant loading to streets. Street sweeping was carried out weekly in all areas. They examined the content of sweeper hoppers and found sweepings to be high in pathogens, along with metals and organic matter (COD). They sampled stormwater outfalls from residential, commercial and high-traffic catchments within 30 minutes of rain by grab sampling. They were able to associate low metals levels in runoff with high metals content in sweepings, but found considerable variation in most parameters. They attributed the variation to the presence of construction activities, length of antecedent dry periods and with winter operations.

With NPDES Phase II requirements being developed, many municipalities were looking at purchasing street sweeping equipment which could remove debris and particulate matter from the road before it entered the drainage system. Brzozowski (2006) provided examples of programs in San Antonio, Texas and Fort Myers, Florida. New street sweepers cost in the range of US\$150,000-250,000, so smaller municipalities which find the costs too high, may consider outsourcing (contracting) the work. San Antonio has seen rapid urban development and their street sweeping requirements have grown considerably. From an original fleet of just 6 sweepers (2 regenerative air and 4 conventional mechanical) the city has expanded to 20 regenerative air TYMCO sweepers, which they plan to replace every 10 years. Revenue was generated by a stormwater utility fee (US\$3-4/household/month). Concerns over dust generation and sweeping in built-up areas were expressed at the regular meetings and discussions with staff, which

helped reduce confusion and keep on top of changes and challenges. They estimated a 10% reduction in solids loadings to receiving waters could be expected as a result of sweeping. In Fort Myers, the City was challenged by dust problems as a result of heavy construction, so consultants recommended customizing the sweepers for the local conditions by fitting them with extra water sprays and larger capacity water tanks. They used mainly Elgin Whirlpool vacuum air sweepers. A Schwarze regenerative air sweeper, which met PM₁₀ requirements, was anticipated to remove fines which contain heavy metals, phosphates and other NPS pollutants. It was recommended that municipalities considering street sweeper purchases arrange for demonstrations of each potential bidder so their staff could properly evaluate these sweepers in the unique environments in which they would be operating.

1.1.5 Fact sheets and guidance manuals include street sweeping as a potential source control measure

Based on information from a number of studies using updated equipment, many government agencies determined that effective street sweeping programs could start to have some effect on the receiving water quality. This new information led to updates or revisions to a number of fact sheets and guidance manuals which now provide suggestions and guidance for operating effective street sweeping programs.

The WEF and ASCE manual (1998) included street sweeping as a potential source control method in runoff quality management. With advancements in sweeping technologies at the time, sweepers were better able to target the fine particles which contain high levels of pollutants. In the manual, they developed some specific recommendations to optimize the effectiveness of a street sweeping program: a) prioritize street cleaning in areas with the highest pollutant loadings, using the most sophisticated sweepers at the highest frequency; b) optimize the cleaning frequency based on storm inter-event times; c) increase frequency of street cleaning prior to rainfall; d) ensure equipment is well-maintained and e) keep good records of the sweeping operation to monitor its effectiveness and make changes where necessary. These recommendations were echoed in most of the recent manuals and fact sheets.

The Terrene Institute (1998) identified the types of sweepers which were available at the time (mechanical, vacuum-assisted wet, regenerative air, tandem, vacuum-assisted dry) and indicated their relative merits. The conclusions were that vacuum assisted wet sweepers could only reduce pollution by 5 to 30%, but dry vacuum sweepers could potentially achieve 35 to 80% reduction of non-point pollution with 15 to 40% reduction of nutrients. Scrubbers (using water and brushes to scrub the pavement and then a vacuum to lift the water away) had very limited applications, but also appeared to work quite well overall. The development of the technologically improved sweepers was providing a much larger array of equipment from which municipalities now had to choose.

The Minnesota Metropolitan Council (2001) published a BMP manual in which they identified street sweeping as a preventative measure to prevent solids, salts and other

pollutants from washing into the stormwater system. They recommended that street sweeping should be combined with prompt pavement repair, spill cleanup and appropriate snow management in order to be the most effective. Although street sweeping was done primarily for aesthetic reasons (removal of coarse particles, leaves and litter), they anticipated that it also had the capability to reduce sediment loading into runoff and decrease maintenance costs. They recommended a minimum frequency of twice per year, particularly in the early spring to collect sand / salt and winter debris and in the fall to capture leaves. Late spring sweeping when seeds have been dropped from the trees should be able to remove a large source of phosphorus from the runoff. Broom sweepers were found to be less expensive to purchase and could pick up wet material, but were also found to generate more dust. Vacuum sweepers were found to be better for fine particles but were ineffective for wet material. They also recommended recycling the salt and grit which was swept from roads in the spring by screening and incorporating them with the new material. They further noted that some road sweepings may be contaminated to the point where they need to be placed in secure landfill facilities, which could further add to disposal costs.

The Ontario Ministry of the Environment (MOE) (2001) published a Street cleaning fact sheet as part of the Stormwater Pollution Prevention Handbook. It indicated that street sweeping may be beneficial in stormwater management. Ideally, sweeping was done using the most technically advanced sweepers, with the greatest frequency in areas with the highest pollutant loading. Optimization of street cleaning frequency (1 to 2 times between storms) was found to remove up to 50% of street dirt. Sweeping by conventional mechanical sweepers was not able to remove more than 15% of fine particles. Sweeping programs were designed to target sediments, nutrients, heavy metals, floatable materials and oxygen demanding substances in order to protect aesthetics and aquatic life, and to reduce sediment contamination. They listed parking enforcement as an important method which could be used to improve the efficiency of the program and that careful attention to maintenance and operational records were important to a well-run sweeping operation.

The US DOT (Department of Transportation) also stated that street sweeping was a useful option in highly developed areas where BMPs may be less effective or land availability reduced (Shoemaker et al., 2002). They indicated that biweekly sweeping could potentially remove up to 80% of road solids and their associated contaminants. They recommended using vacuum assisted sweepers which follow behind mechanical sweepers (a tandem operation) to provide improved particle capture ability. This could also be achieved using the Enviro Whirl Technologies Inc. machines which incorporated both a mechanical sweeper and a vacuum into a single unit.

The California Stormwater Quality Association (CASQA), (2003), has also published a BMP manual which incorporates street sweeping to improve runoff water quality and also improve air quality by removing a source for dust. They suggested that street sweeping should occur at a minimum frequency of once per month (for all streets), in dry weather where possible, using dry techniques and with advanced sweepers (either vacuum or regenerative air machines). Increased frequency (up to daily sweeping)

should be considered in areas with high traffic, industrial operations, excessive accumulation, or if they drain into sensitive receiving waters. Sweeping should be performed in advance of rainfall so that sediments are removed before they can be washed off. Parking restrictions should be enforced to keep streets clear during sweeping operations. They advised that street sweepers need regular maintenance and should be inspected for wear or leaks, to maintain optimum sweeper efficiency. They should be substituted with more modern equipment when replacement becomes necessary. It was also recommended that an operator training component be included in a good street sweeping program and that accurate logs needed to be kept in order to highlight any ongoing issues or deficiencies. Street sweeping programs should be designed to target the sediments from construction areas and to contain and clean up spills in order to prevent this material from reaching the receiving waters.

The Ramsey-Washington Metro Watershed District investigated the potential for street sweeping to be included in their BMP requirements (Schilling, 2005a). This was a comprehensive report on the state of street sweeping technology and addressed research needs for street sweeping and possible means of applying street sweeping as a source control measure in stormwater management. An annotated bibliography of 48 papers and reports on street sweeping were included. The major conclusions reached in this study were that street sweeping technologies and practices have reached the point where it is possible to come close to achieving the goal of having significantly cleaner street surfaces prior to rain or snowmelt events. They determined that mechanical sweepers were effective for removing coarse materials and gross pollutants but not fines, and the mechanical sweepers may end up exposing these fines after sweeping, making it easier for them to be washed off during rain events. High efficiency sweepers may increase the removal of total solids by 30 to 70%. Sweeping monthly to twice-weekly was found to be the most effective frequency for pollutant removal. As municipalities develop stormwater pollution plans, sweeping will likely become a favourable option as a non-point source control measure. They determined that additional research was needed to obtain more information on water quality improvements from sweeping. Improvements to fuel efficiency, use of waterless sweepers, new technologies (e.g., captive hydrology) may also be forthcoming and could provide significant improvements to sediment capture rates. Manufacturers may also respond to the introduction of state or federal regulations and requirements for advancing technologies. High-efficiency street sweeping when combined with other BMPs can be effective at controlling downstream pollution and it also helps to extend the life of the BMP, reducing ongoing habitat deterioration. However, there were no definitive results where water quality improvements have been demonstrated as a result of street sweeping alone. Sweeping in commercial areas was likely to remain a priority, but sweeping in residential areas more often than twice per year was considered unnecessary. Modelling has revealed that it is important to address sediment removal effectiveness rather than equipment costs. Further research is needed to determine if high-efficiency sweeping can be related to water quality improvement. Additional research is needed on sweeping as a component of subwatershed modelling, disposal of sweepings and recycling practices, life-cycle costing, and integration of sweeping in local government practices.

As a companion to the above study, a series of recommendations for policy and implementation were created (Schilling, 2005b). The major conclusions and recommendations pointed to the use of vacuum or newer sweeping technologies, with proposed sweeping frequencies ranging from 6 to 104 times per year (depending upon site classification). Fall leaf collection and disposal was found to be a major issue (large amounts of carbon and phosphorus were available to wash into receiving waters if they were not removed). They suggested that sweeping could be put in place in official stormwater management plans to keep materials out of BMPs and help improve water quality. They also found that grants may be useful incentives to municipalities wishing to purchase the expensive new equipment (e.g., up to US\$1 million).

The USEPA has included street sweeping in the series of measures which are available to municipalities to control non-point sources of pollution (USEPA, 2005). This document provides a guideline for local municipalities for the control of urban pollution. It recommends the implementation of street sweeping measures to ensure the maintenance of drainage structures and to act as a source control measure for urban runoff pollution (particularly for TSS and associated pollutants) and suggests that up to 80% reduction could be achieved if a well-run sweeping program is in place. It adds that frequency of cleaning should reflect the rate of buildup of pollutants and should increase just before the rainy season to provide maximum benefits. It also adds that operators require adequate training and equipment requires proper maintenance for programs to be effective. Parking restrictions should provide access for cleaning equipment in areas where on-street parking is utilized. They recommend using vacuum-assisted sweepers where possible, which most municipalities have found cost less to operate (approximately 50%) per curb km than conventional mechanical sweepers, along with a greater expected lifespan.

The USEPA (2007) also created an updated series of fact sheets to address the NPDES. They strongly supported the findings of CASQA (2003). This online fact sheet provides guidance for municipalities who wish to add street sweeping as part of their municipal activities for pollution prevention and good housekeeping. Removal of pollutants including sediment, debris, trash, road salt and trace metals, as well as improvements to aesthetics, control of dust and a decrease in solids accumulation rates in catchbasins were some of the benefits. By decreasing the amount of pollutants on the roads, it is possible to reduce the pollutants in surface waters. Using street sweepers could reduce the need for other structural BMPs, particularly in high-density urban areas with larger areas of pavement. In cold climates, it was recommended to sweep during the spring snowmelt (or at least as soon as the snow has melted and prior to heavy spring rainfalls which will be more likely to mobilize pollutants) in order to reduce pollutants in stormwater runoff, particularly those from salt, sand and grit. They suggested using a schedule which should be flexible enough to accommodate weather related changes and extra attention in areas of concern. Schedules could be adjusted by careful accounting of sediment and trash accumulation rates and factoring-in the proximity of certain sites to surface waters or sensitive areas. They recommended targeting areas which have high levels of imperviousness, traffic or industrial activity, where pollutant concentrations would be highest, as well as those roads where large accumulations occurred quickly and needed

frequent sweeping to keep road solids within set limits. Operation and maintenance issues were found to be very important with street sweepers. Regular maintenance would be vital to reduce down time and maintain sweeper efficiencies. There was a strong need to develop a plan and budget for equipment replacement; most sweepers have a 5 to 8 year life span and this would allow the replacement of older equipment with the most technologically advanced sweepers. The cost of cleaning was found to be US\$42/curb km including all O&M costs (in 1995 US\$).

With further advancements in the efficiency of street sweepers, 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 Street Sweeping Issues

Some municipalities regard street sweeping simply as a form of litter control (Walton, 1988), while others apply sweepers in order to improve air quality issues (Clean Air Hamilton, 2001; Kuennen, 2001). New requirements for controlling urban runoff pollution and advancements in street sweeping technology have lead other municipalities to apply street sweeping programs as a first line of defense for stormwater BMPs (Taylor and Wong, 2002; City of Roseville, 2005; Muhammad and Hooke, 2006). 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 reduce the presence of winter accumulations of sediment prior to washoff by spring rains. 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, which 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 operational 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 (Schilling, 2005a).

Industrial areas such as North Hamilton, Ontario, where heavy industries operate, (including coal-fired steel plants), 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 many benefits aside from litter control (CASQA, 2003).

Stidger (2003) reported a number of best practices for street sweeping, adapted from St. Paul, Minnesota. These included the proper training of operators and maintenance workers, optimizing shift times (e.g., overnight sweeping of downtown business areas and parking lots), 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 clean 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 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 achieve a reasonable efficiency of silt removal from paved road surfaces under various modes of operations. The cost of the increased street sweeping effectiveness was identified as a critical factor in decision making, since cleanup of sediment from creeks and sewer pipes due to solids washing off roads could be more costly than purchasing and maintaining a high-efficiency sweeper.

Street sweeping may be a useful tool in stormwater management, though the benefits are hard to prove. Models are often used to simulate improvements as a result of street sweeping program implementation, however data is still limited and further information and monitoring is needed to support and improve the choices made in model parameter selections (Breault et al., 2005). Sweeping is a management measure with immediate benefits; other measures, like ponds and wetlands, can take years to build and significant investments of time and money are required to construct, monitor and maintain them. Stopping pollutants at the source removes the pollutant before it becomes 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. In commercial or industrial areas where pollutants are more prevalent, street sweeping can be most effective if the streets are free of parked cars, but this becomes considerably more difficult in residential areas with on-street parking (WEF & ASCE, 1998; MOE, 2001; CASQA, 2003; 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 C\$150,000 for used equipment to more than C\$300,000 for PM_{2.5} 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.

1.3 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 the Water and Wastewater Division) and Transportation Services Division. The City of Toronto wished to assess the impacts to local air quality and the health risks posed to the motorist, cyclist and pedestrians travelling along the City of Toronto streets by fine particulate matter located on the street surface. Such material could easily be resuspended by traffic, but these risks could potentially be reduced by efficient street sweeping. One of the additional benefits could include improved stormwater quality (Kelman and Crowther, 2005). 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 (City of Toronto, 2003). 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.

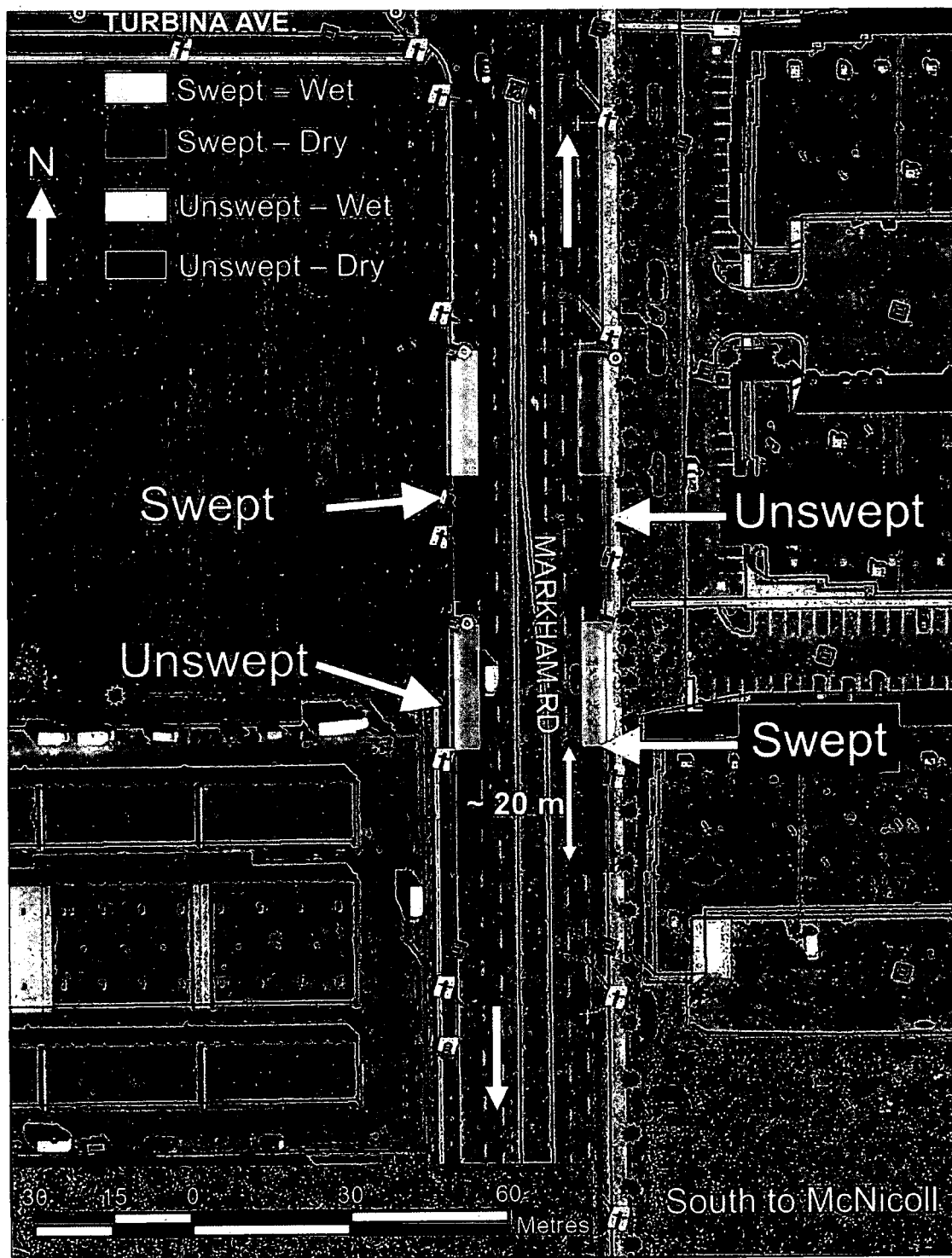


Figure 2.1: Markham Road site paired test catchment areas

2.2 Street Sweepers Employed

Three different types of street sweeper were used between July and November over a three-year period (2004 to 2006): 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 and 2.5). In 2004, two types of street sweeper were used; 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. These two types of sweepers make up the majority of the City of Toronto fleet. In 2005, only one type of street sweeper (a new-technology regenerative air sweeper) was used, so it cleaned both the northbound and southbound lanes, which doubled the number of test results (see Figure 2.4). For 2006, a brand-new City-operated, new-technology regenerative air sweeper was employed (see Figure 2.5). The City has planned to replace its aging sweepers with the new high-efficiency versions, as part of potential source control measures to be implemented under the new Wet-Weather Flow Management Master Plan (City of Toronto, 2003).

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. In 2005, and older model (not maintained by the City) was used, but in 2006 a new City-customized model was available for testing.



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 used in 2005



Figure 2.5: New-technology regenerative air (NRA) sweeper used in 2006

2.3 Field Sample Collection Methods

During the testing period (June 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 an antecedent dry period of seven days was based on a survey of 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 (an average accumulation rate of 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] (an average accumulation rate of 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.

Generally, a steady state for road deposited sediment could be reached within seven days (e.g., Sartor and Boyd, 1972; Ball et al., 1998, Pitt et al., 2004; Breault et al., 2005). It was also recognized that even after 3 days, most of the pollutant buildup was likely to have occurred. 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 (June to November), 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 than originally planned. 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 all three field seasons (2004, 2005 and 2006) are presented in Table 2.1.

In order to better assess and understand the effectiveness of street sweeping, both wet and dry samples were collected. Figure 2.6 provides an overview of parameters sampled and methods used. Detailed descriptions follow.

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 ¹	8	8	0
October 7, 2004 ²	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
July 18, 2006	3	5	68.8
August 10, 2006	6	7	26.4
August 22, 2006	7	19	26.4
September 26, 2006	0	7	19.8
October 18, 2006	0	0	51.0
November 22, 2006	4	5	31.6

¹ - 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.

² - 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.

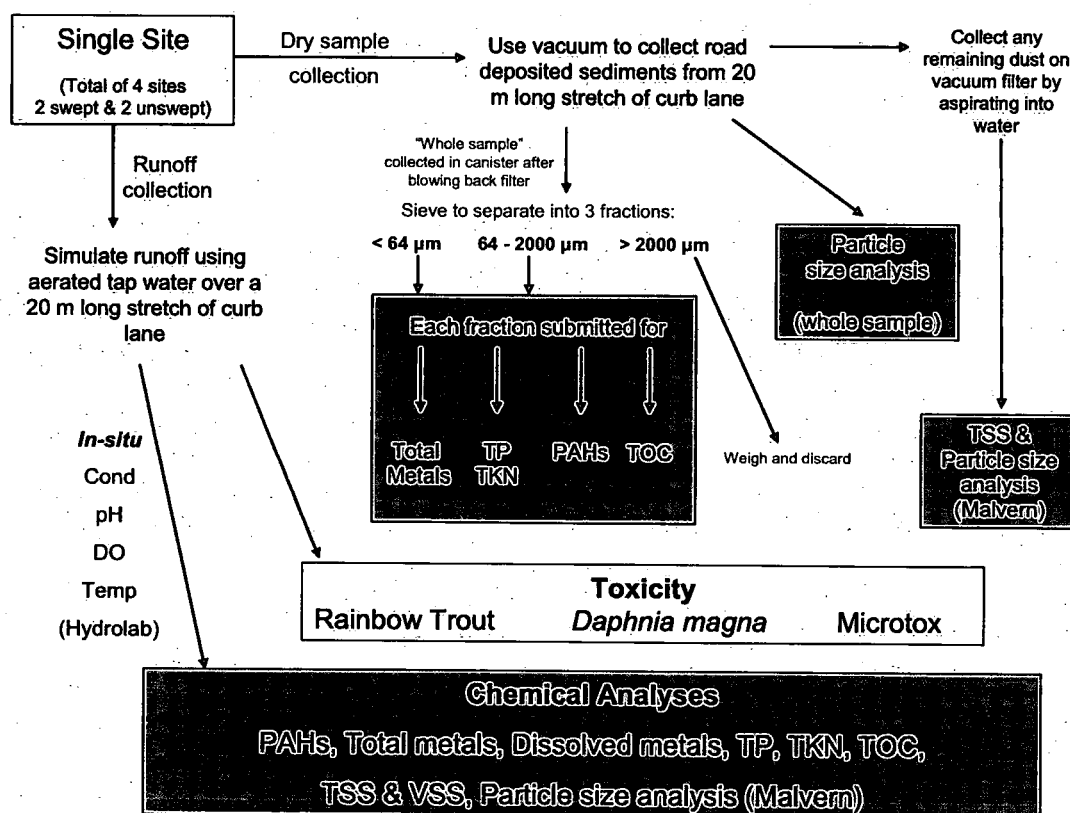


Figure 2.6: Overview of sampling procedure and analyses

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 lanes were sampled at these sites, since studies have shown that almost all road deposited sediment and litter accumulate within 1 m of the curb (Sartor and Boyd, 1972; Novotny, 2003). An area of asphalt pavement and concrete curb, 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 concrete curb edge 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 2.7 and 2.8 show the road deposited sediment sample collection being performed in the field and Figure 2.9 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 and 2006, 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 during the 2005 and 2006 field seasons. The solids which remained on the 3 μm filter pleats were carefully vacuumed off through a series of two flasks, each filled with 1L of distilled water (Figures 2.10 and 2.11). This allowed the determination of the total mass of fine solids adhering to the filter (via a total solids test), and prepared the sample for further analysis using the Malvern laser particle size analyzer (limit of detection < 2.9 μm). Compressed air was used to clear any dust remaining on the filter before reuse.



Figure 2.7: Road deposited sediment sample collection

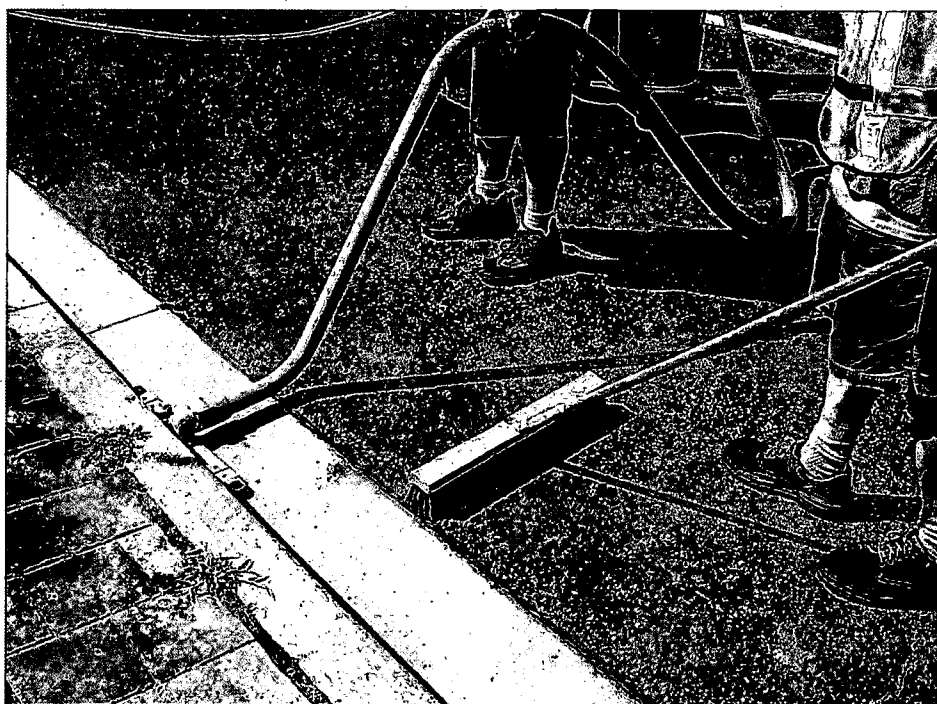


Figure 2.8: Sampling road deposited sediment along the curb



Figure 2.9: Example of road deposited sediment sample collected over 20 m length of curb lane

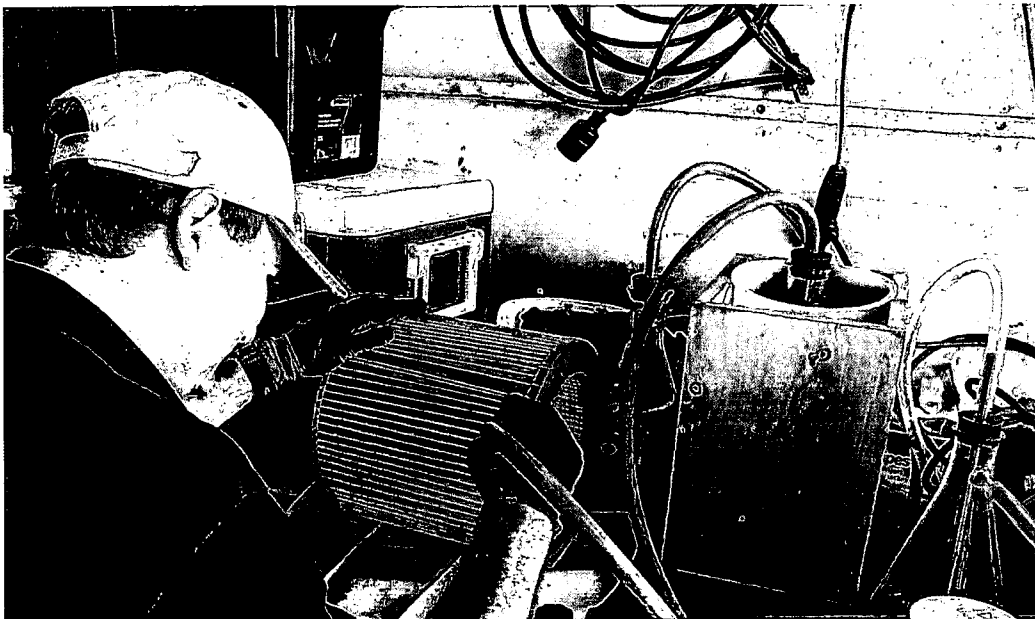


Figure 2.10: Filter pleats being vacuumed off into water flasks

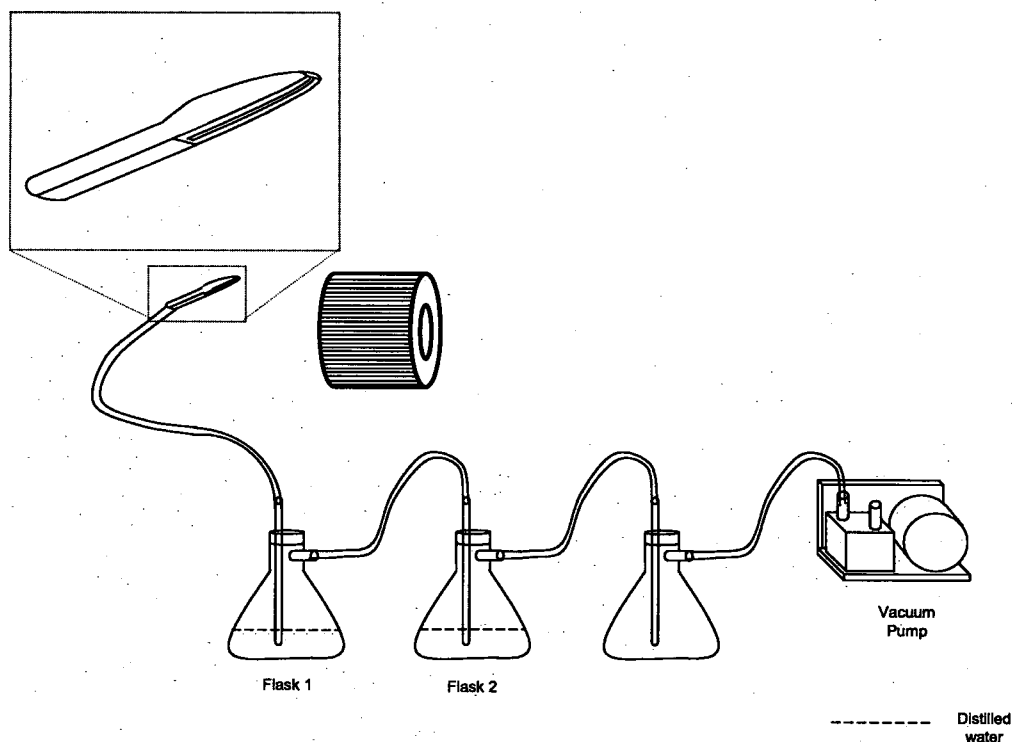


Figure 2.11: Filter vacuum system with specialized crevice tool and water flasks connected to vacuum

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 2.12). 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 2.13.



Figure 2.12: Catchbasin insert installed in manhole and wand of wash down device showing simulated runoff generated



Figure 2.13: Wet sample collection – test catchment area

There were some minor technical problems identified during the 2004 field season, so a few changes were proposed and adopted for the sampling techniques in 2005/2006. One of these improvements included the use of a larger catchbasin insert. The original insert, 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 insert 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 insert (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 introduced 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: $i = 12.7 \text{ mm/h}$). This new configuration is shown in Figure 2.14 and 2.15. Wash water was also acidified in 2005/2006 runs. After dechlorination, a concentrated mixture of 60% H_2SO_4 : 40% 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 the target of pH 6

was never reached. The buffering of the wash water usually raised the pH to > 7.0 by the time the water was used on-site.



Figure 2.14: Wet sample collection – water broom

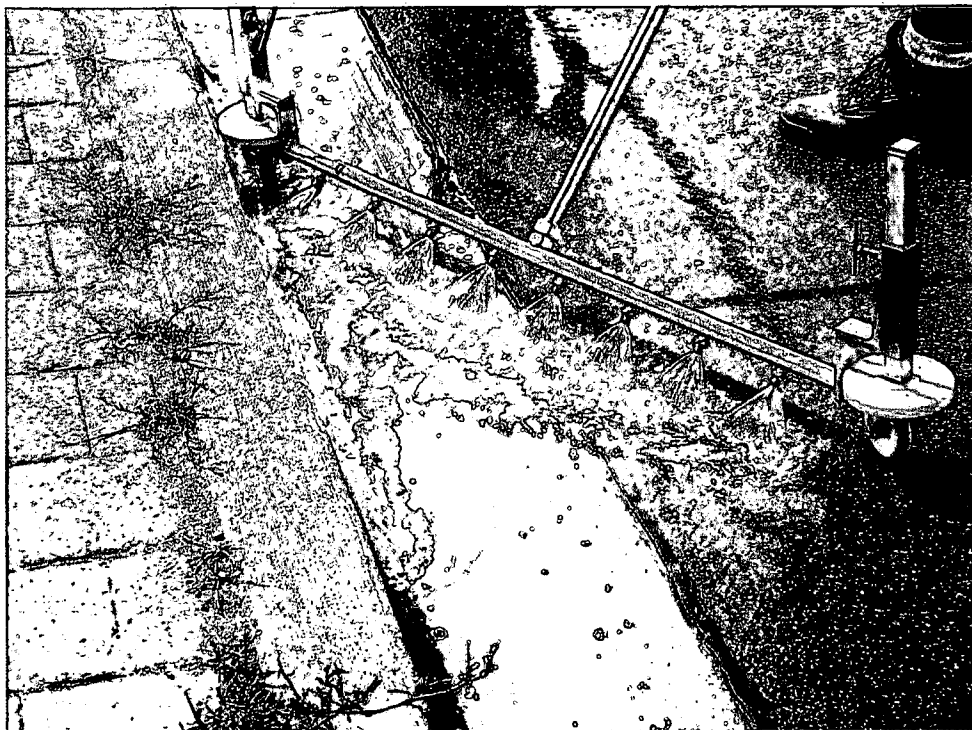


Figure 2.15: Water broom – detail of nozzles and curb washing technique

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 and 2006 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 uses a set of varying gauge sieves (down to $63\ \mu\text{m}$) and a known mass of sample. 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 whole 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 (Ca, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Na, and Zn), total phosphorus, total nitrogen, total organic carbon and PAHs (16 U.S. EPA priority 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 for 20 minutes. 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 runoff samples collected in the field were immediately preserved and placed on ice. Once returned to the lab, the samples were transferred to a refrigerated storage room at 4°C, where they remained until analyzed.

2.5.2 Runoff toxicity

Approximately 60 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 three years of field research at the test site on Markham Road in Toronto. For all of 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 and in the following section, any "significant" results refer to standard error. Due to the high variability of the data encountered, when the 95% confidence limits were applied to the data analyses, very few statistically significant differences could be established between any of the swept and unswept sites. Some significant results were obtained for some parameters when compared between years or between northbound and southbound lanes, but not between treatments.

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. These sites were used as controls for the swept sections of curb lane during testing. 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 three years).

The sand fractions dominated the composition of the samples, with a range between 54% and 91%, and an average of 71% of the total mass. Less than six percent of the mass of the sample was contributed by the silt + clay fraction (4.2% on average) and gravel accounted for between 4 and 42% (25% on average) of the total 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%).

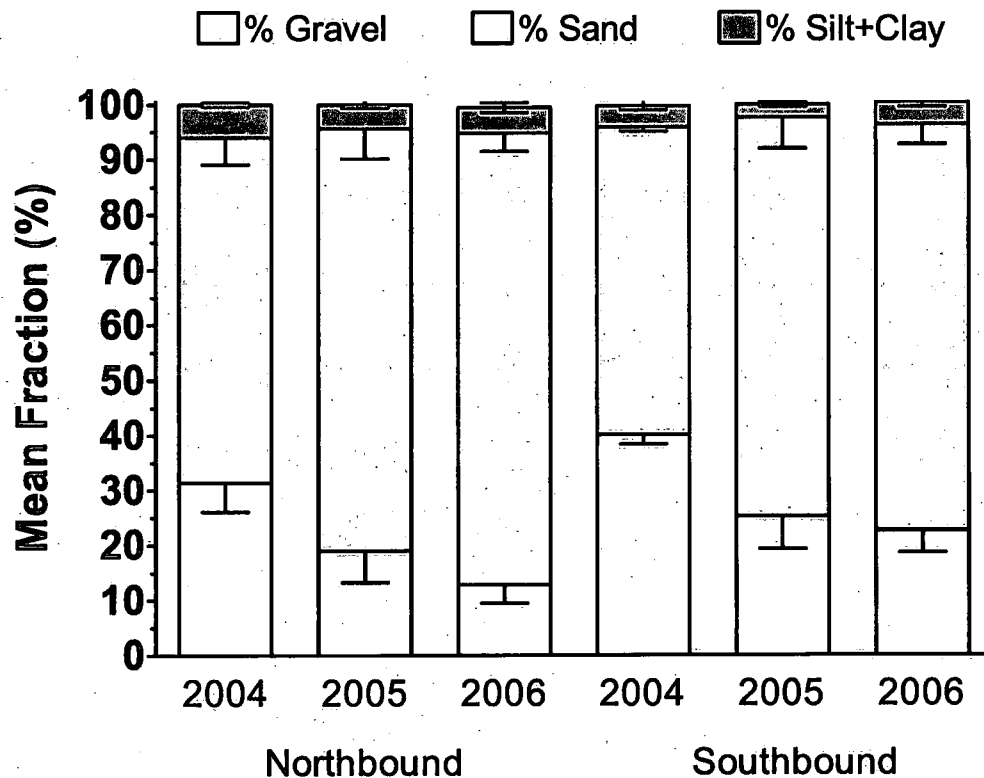


Figure 3.1: Overall characterization of road deposited sediment by sediment class (northbound [NBUS] and southbound [SBUS] unswept sites)

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 more gravel on the southbound lanes in all years. The amount of gravel on the northbound lanes decreased over the 3-year study, although the year-to-year changes (i.e., 2004 to 2005 and 2005 to 2006) were not significant. At 95% confidence limits, none of these means could be considered significantly different. Sand was a major component of all samples collected from these sites, comprising between 25 to 200 kg/curb km of the total sediment load (Figure 3.3). Northbound lane samples showed a relatively constant 25 kg sand/curb km; the southbound lanes appeared to increase steadily over the years to roughly double the 2004 levels. Silt and clay in the northbound lanes also showed nearly constant levels (around 2 kg/curb km). The southbound lanes were normally higher (around 4 kg/curb km), but in 2006, the load more than doubled (10 kg/curb km).

Based on field observations, a number of active construction sites were located north of the research area and construction debris (which would include all three fractions of solids) 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.

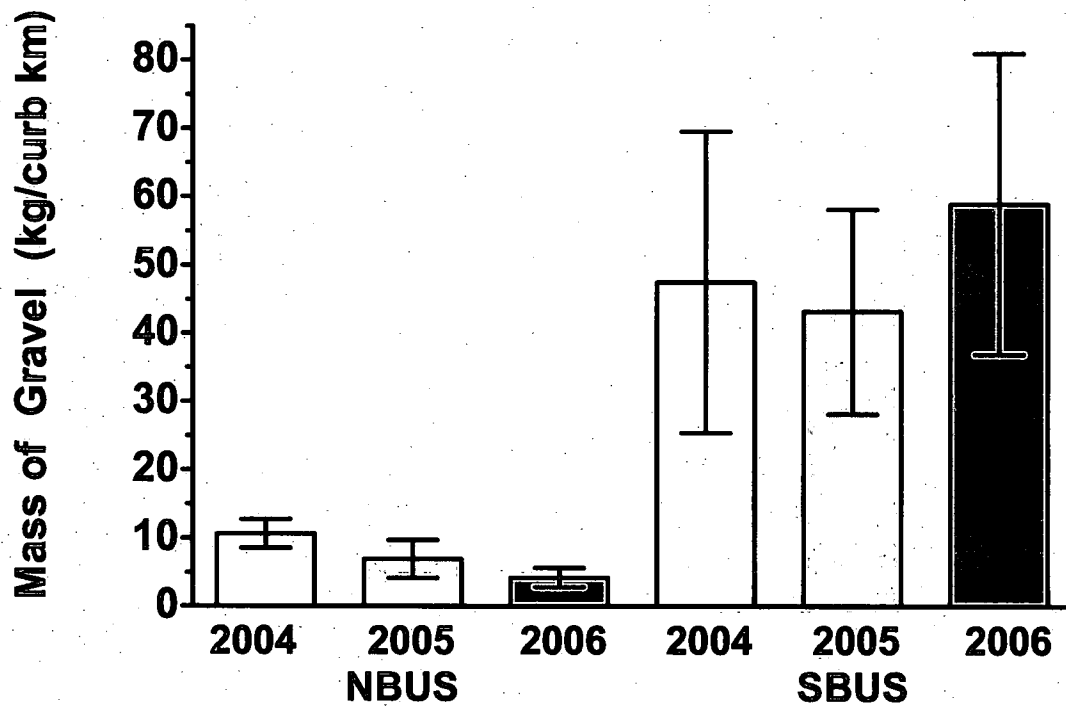


Figure 3.2: Mass of gravel in road deposited sediment material (northbound and southbound unswept sites)

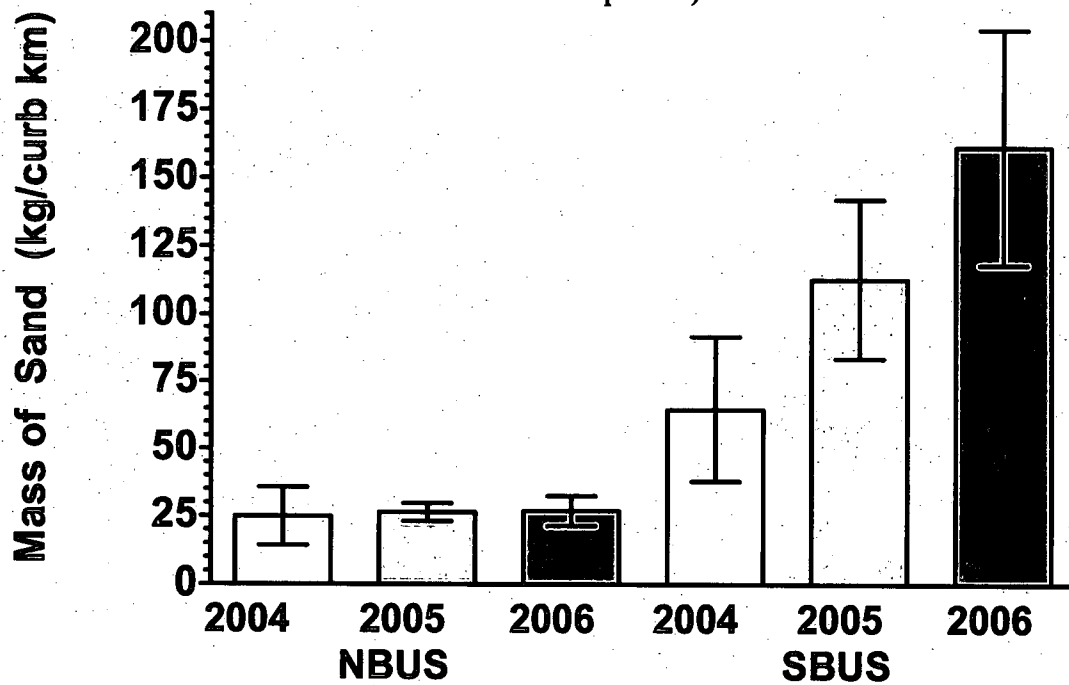


Figure 3.3: Mass of sand in road deposited sediment material (northbound and southbound unswept sites)

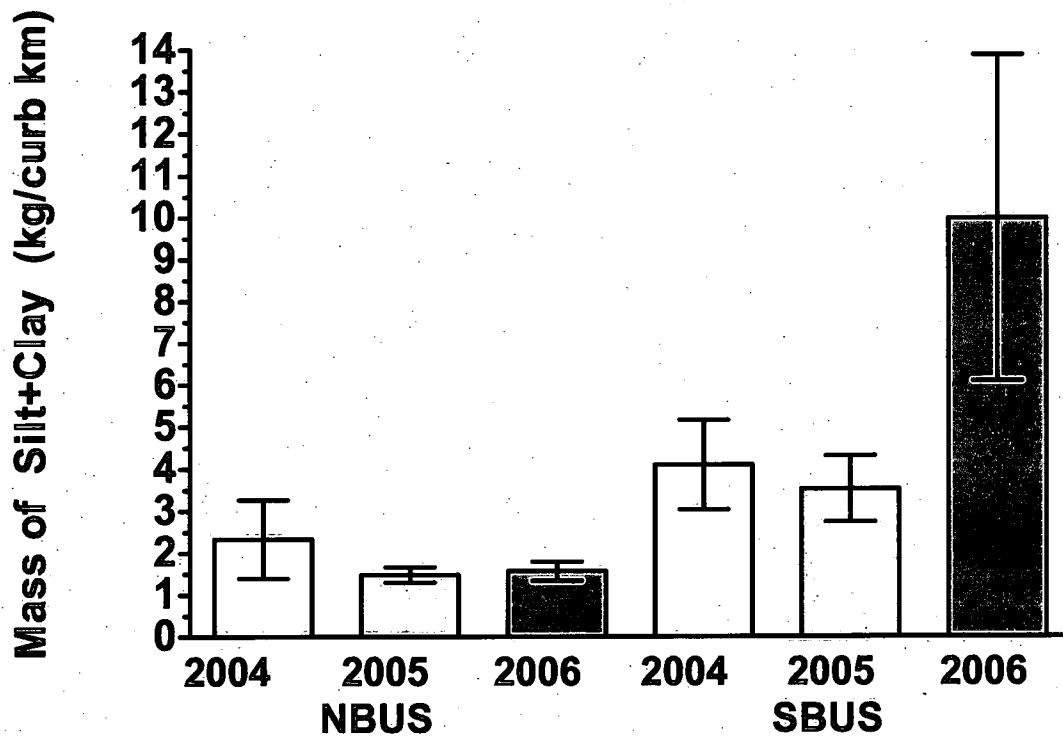


Figure 3.4: Mass of silt + clay in road deposited sediment material (northbound and southbound unswept sites)

3.1.2 Mean particle size

Figure 3.5 compares the mean particle size for northbound and southbound lanes for 2004 to 2006. In 2004, there was a significantly larger mean particle size southbound (1248 μm) compared to northbound (944 μm), but this difference was not evident in 2005. In 2006, mean particle size was lower for both northbound and southbound when compared to 2004 data. The southbound lanes had a significantly greater mean particle size of 761 μm compared to the northbound lanes at 544 μm . When the data from all three years was pooled together, however, only a slight difference was observed (which was not significant at 95% confidence) for mean particle size between either location (see Figure 3.6).

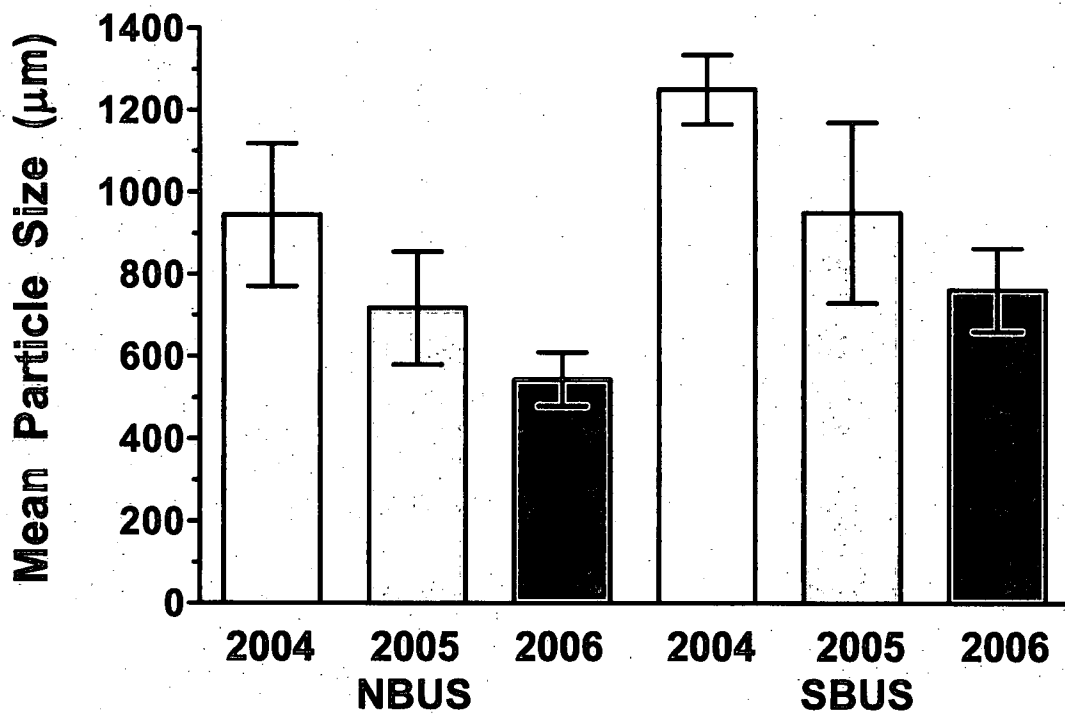


Figure 3.5: Mean particle size (northbound and southbound unswept sites, 2004 and 2005)

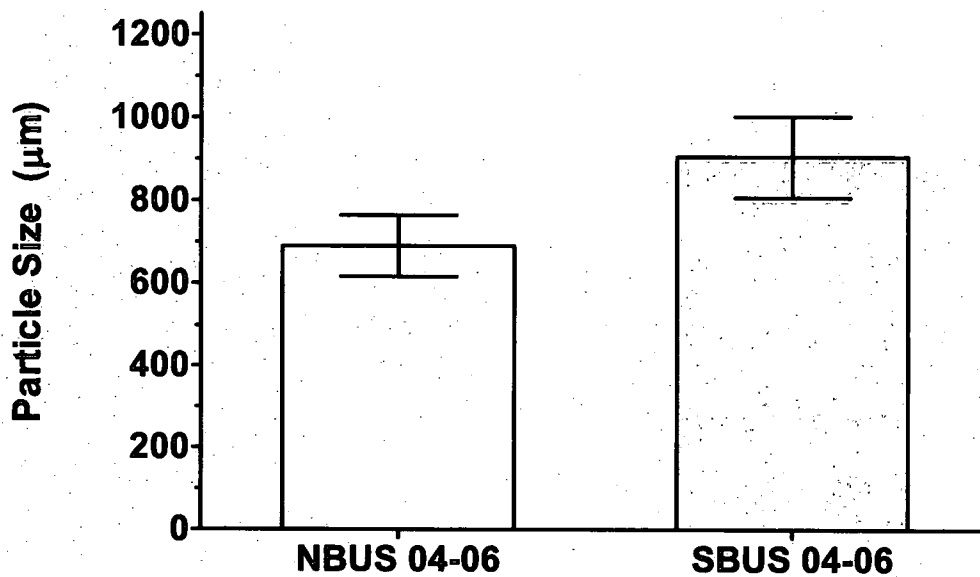


Figure 3.6: Mean particle size (combined northbound unswept sites 2004-06 and combined southbound unswept sites 2004-06)

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 in 2004 and one interval in 2006 between sampling events were without any rainfall. These completely dry periods (where the road surface had been previously well-cleaned by the industrial vacuum during prior sampling), could be used to estimate road deposited sediment accumulation rates. This accumulation results from a combination of many factors, including transport from adjacent areas, wind deposition and erosion, vehicular wear and tear, and the degradation of the pavement surface (Pitt et al., 2004). The estimation methods used and the range of values obtained are described below. Although it is almost certainly not valid to assume that the buildup occurs predictably over time, other researchers have found it useful to compare sites and to other studies. Impacts from wind, weather, traffic patterns, construction, size of sampling area etc., would likely cause variations in the rate of accumulation, which would be quite difficult to account for.

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 m², with a curb length of 20 m). Assuming that the buildup occurred uniformly over time, an accumulation rate could be calculated as:

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

Substituting the above numbers into equation 3.1 yields a value of 3.2 kg/curb km/d (total mass = 516.5, curb length = 20 m and time = 8 days). If it was assumed that the accumulation rates 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 kg/curb km/d (all other parameters remain the same, but 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 m², with a curb length of 20 m). Again, using equation 3.1, this resulted in an accumulation rate of 6.6 kg/curb km/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 kg/curb km/d. In 2006, both northbound and southbound lanes were sampled after a dry period of 12 days (between 10 August, 2006 and 22 August, 2006). A total of 359 g of sediment had built up on the northbound lanes (80 m²) in 12 days, so the estimated accumulation rate was 1.5 kg/curb km/d. Again, if this were assumed to occur over just 3 days, the accumulation rate would be as high as 6 kg/curb km/d. On the southbound lanes 909.5 g of sediment had accumulated, so the estimated accumulation rate was 3.8 kg/curb km/d. If this were estimated to occur over just 3 days, the accumulation rate would be adjusted to 15.2 kg/curb km/d. The literature suggests that 9 kg /curb km/d could be considered an average accumulation rate for residential / commercial streets in good condition, and the expected range fell between 1 and 40 kg/curb km/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 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 kg/curb km. 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. In this study, the RDS was sampled using a manual push-broom and a high-efficiency industrial vacuum cleaner; other studies used in this comparison employed slightly different techniques and would be expected to return different results. Experiments in the laboratory showed that the vacuum used in this study was capable of picking up fine material (3-10 μm) at 97% efficiency from concrete in good condition (Fralick, 2005).

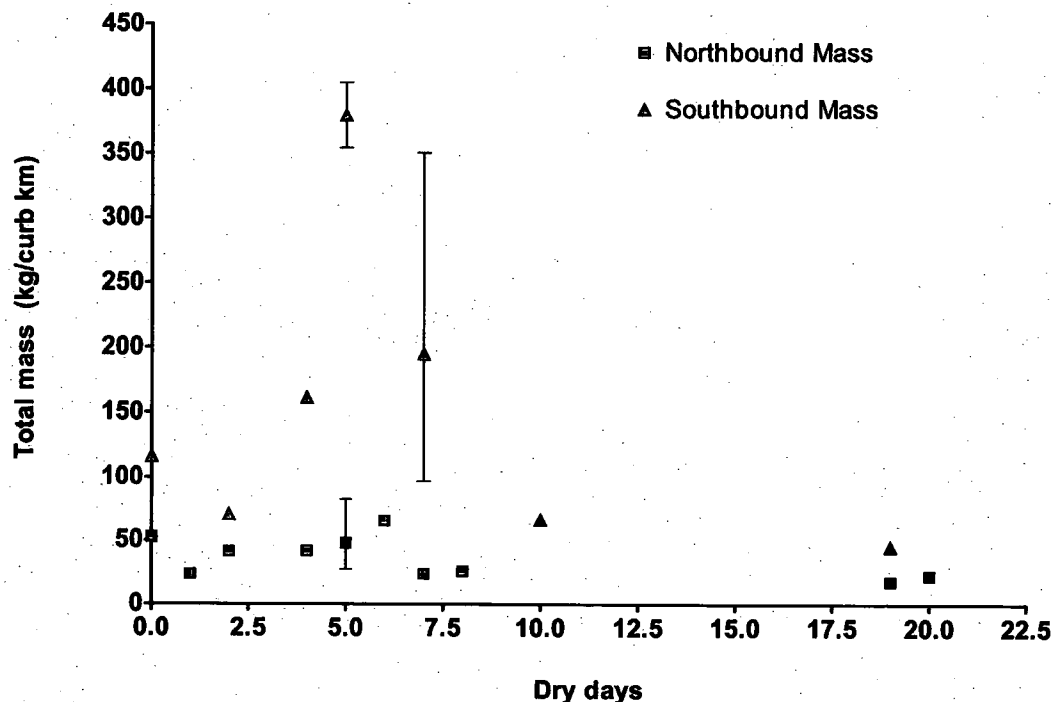


Figure 3.7: Mass of road deposited sediment (RDS) collected by vacuuming at unswept sites (Error bars indicate the span of multiple points for the same number of dry days)

3.1.4 Sediment loads on unswept areas

Although sediment particle size distributions were not different between northbound and southbound lanes, total dry sediment loads collected by industrial vacuum were significantly different. This result was also significant at the 95% confidence level. There was no difference between years (2004, 2005 and 2006), but the mean sediment load (combining the data from all three years) was 34.9 kg/curb km for northbound lanes and 167.8 kg/curb km in the southbound lanes (see Figure 3.8). This approximately 5 times greater loading was likely due to the transport of construction debris from sites located just to the north of the test area.

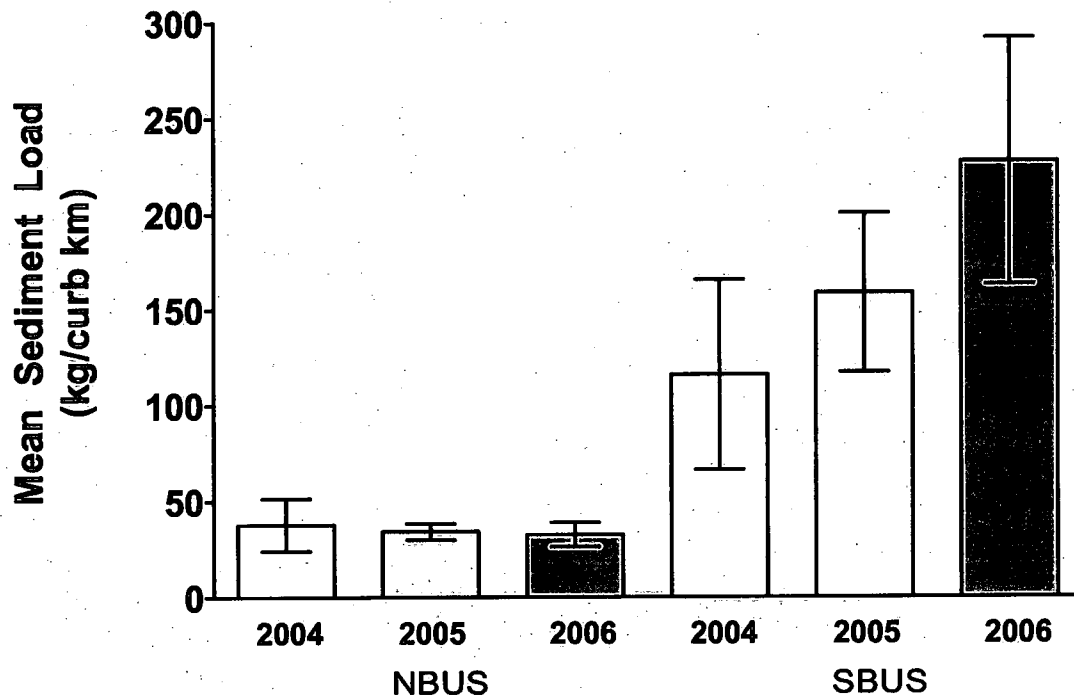


Figure 3.8: Mean sediment load (northbound and southbound unswept sites)

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 10.4 μm 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 removed between 4 and 6% of the total sediment load available on the road.

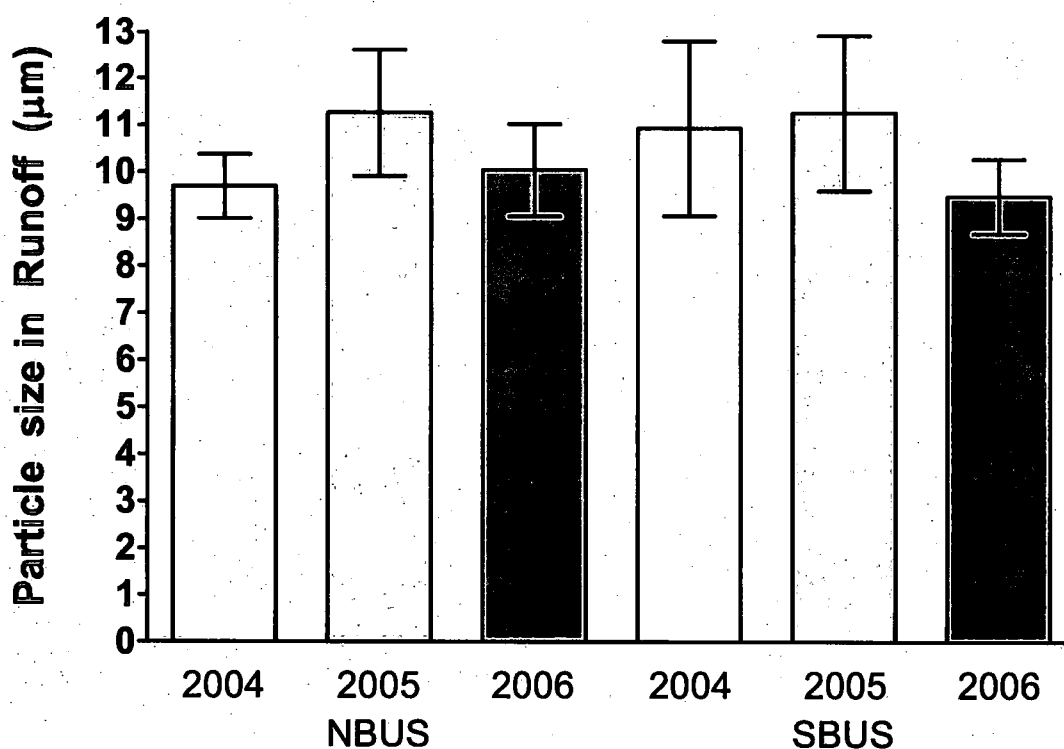


Figure 3.9: Particle size in runoff samples (northbound and southbound sites - 2004 to 2006)

3.1.5 *Transport of sediment under simulated runoff conditions*

Total suspended solids generated by simulated runoff were measured for samples collected from the catchbasin insert. 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 x TSS of runoff / 20 linear curb m = total solids washed off road) was used to standardize the results. Of particular interest was the variation experienced in samples collected during this study. In some cases, e.g., SBUS 2006, the variation was extreme, ranging from 11.8 to 73.8 kg/curb km. It was noted that the amount of solids washed off each test catchment (NBUS and SBUS) was 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 the increase in efficiency perceived by field personnel. The overall mean for all unswept sites and all years was 15.4 kg/curb km. When compared to the mean sediment loading of 101.4 kg/curb km, this represented just 15% of the potential available for washoff. The low fraction of solids collected by washing suggests that the water broom may be considerably less effective in dislodging street surface particles than the combined action of the brush/industrial vacuum (see the Methods section) and/or that the hydraulic transport generated by the water broom was not sufficient to transport the coarser dislodged particles to the inlet sampler.

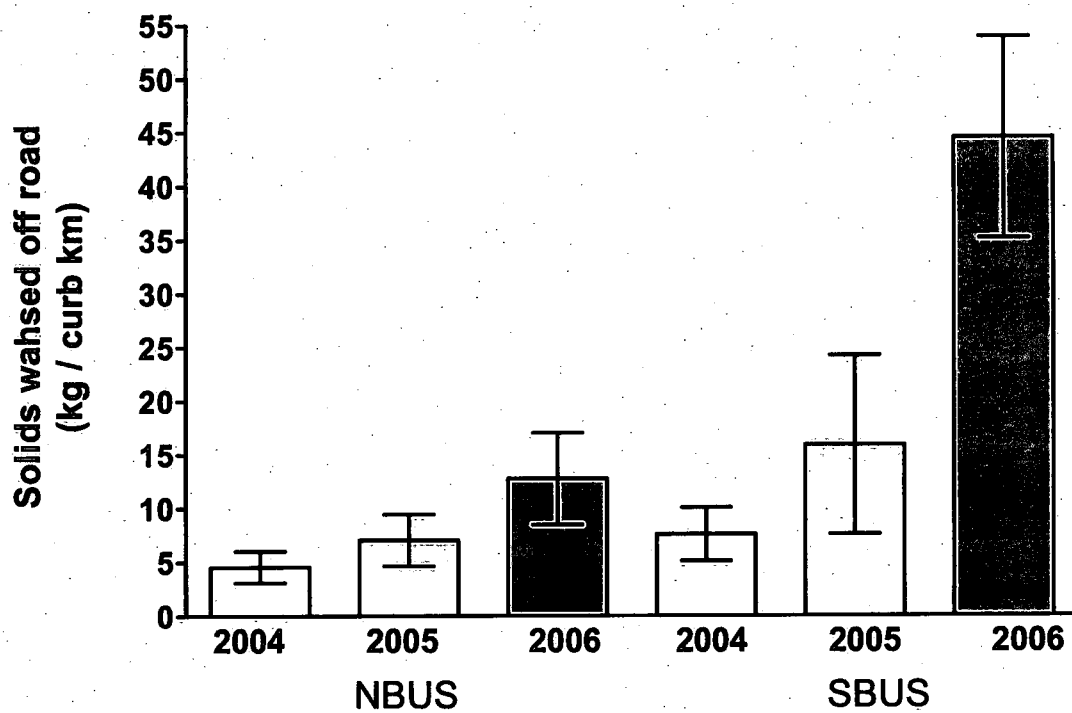


Figure 3.10: Mean weight of solids washed off the road from unswept sites (northbound and southbound sites 2004 to 2006)

3.1.6 Chemical evaluation of road deposited sediment

The chemical characteristics of the road deposited sediment from unswept test sites (NBUS and SBUS) were also evaluated to determine background conditions for dry road deposited sediment. A wide range of chemical components were evaluated (nutrients – Table 3.1, some key metals – Table 3.2 and three PAHs – Table 3.3). The mean for each of the two particle size ranges (<64 µm and 64 - 2000 µm) are listed for each site and year. Early comparisons suggested that there was a difference in the background (unswept) conditions between northbound and southbound lanes. It was for this reason that northbound and southbound lanes were analyzed separately for each year. The data from all three years supported this hypothesis and large variations in values for nutrients, metals and PAHs were observed over the 3 years.

The results show that generally, northbound sites had higher concentrations of contaminants than the southbound sites and, as would be expected, the < 64µm size fraction contained more contaminants per unit mass than the 64 - 2000 µm size range. Some notable exceptions included TP on the NBUS site in 2006, Cu on the SBUS site in 2004 and NBUS site in 2006 and Pb on the NBUS 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)	Total Load (mg/kg)
TOC	2004	NBUS	37,000	14,000	16,070
	2005	NBUS	45,000	21,750	22,913
	2006	NBUS	75,000	46,000	47,740
	2004	SBUS	21,500	9,000	9,875
	2005	SBUS	28,500	11,750	12,253
	2006	SBUS	62,000	48,000	48,700
TKN	2004	NBUS	1,200	353	429
	2005	NBUS	844	289	317
	2006	NBUS	993	274	317
	2004	SBUS	805	250	289
	2005	SBUS	806	163	182
	2006	SBUS	700	240	263
TP	2004	NBUS	823	510	538
	2005	NBUS	820	493	509
	2006	NBUS	781	929	920
	2004	SBUS	720	465	483
	2005	SBUS	870	465	477
	2006	SBUS	762	444	460

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 (Table 3.2), 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 probable effect level [PEL] and / or the provincial severe effect level [SEL]).

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

	ISQG ¹	PEL ¹	LEL ²	SEL ²	Yr.	Location	< 64 µm	64 – 2000 µm	Total Load	Stone & Marsalek ³	Skyway Sediment ⁴
	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)			(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Cr	37.3	90	26	110	04	NBUS	69	61	68	92.4	---
					05	NBUS	180	120	130		
					06	NBUS	174	115	126		
					04	SBUS	46	53	57		
					05	SBUS	140	80	85		
					06	SBUS	88	61	66		
Cu	35.7	197	16	110	04	NBUS	207	135	155	87.3	314
					05	NBUS	245	160	173		
					06	NBUS	211	344	358		
					04	SBUS	103	196	204		
					05	SBUS	168	81	87		
					06	SBUS	83	65	70		
Pb	35	91.3	31	250	04	NBUS	64	208	215	90.5	402
					05	NBUS	82	49	54		
					06	NBUS	189	61	73		
					04	SBUS	39	45	49		
					05	SBUS	67	29	32		
					06	SBUS	45	24	27		
Zn	124	271	120	820	04	NBUS	507	230	277	227	997
					05	NBUS	625	268	300		
					06	NBUS	529	238	271		
					04	SBUS	265	300	319		
					05	SBUS	463	218	233		
					06	SBUS	233	123	136		

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

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

³ Stone and Marsalek (1996) – whole sediment samples

⁴ Marsalek et al., (1997) – whole sediment samples

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.

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

	ISQG ¹	PEL ¹	Yr.	Location	< 64 µm	64 – 2000 µm	Total Load	Skyway Bridge ²
	(mg/kg)	(mg/kg)			(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Phenanthrene	0.04	0.52	04	NBUS	1.05	0.39	0.45	5.03
			05	NBUS	0.74	0.21	0.24	
			06	NBUS	0.70	0.40	0.42	
			04	SBUS	0.57	0.37	0.38	
			05	SBUS	1.33	0.78	0.80	
			06	SBUS	0.50	0.30	0.31	
Fluoranthene	0.11	2.36	04	NBUS	1.73	0.65	0.75	3.84
			05	NBUS	1.49	0.35	0.41	
			06	NBUS	1.00	0.60	0.62	
			04	SBUS	1.00	0.46	0.50	
			05	SBUS	3.11	1.32	1.37	
			06	SBUS	1.00	0.50	0.53	
Pyrene	0.05	0.88	04	NBUS	1.33	0.52	0.59	2.89
			05	NBUS	1.33	0.30	0.35	
			06	NBUS	0.90	0.50	0.52	
			04	SBUS	0.75	0.46	0.48	
			05	SBUS	2.54	1.05	1.09	
			06	SBUS	0.80	0.40	0.42	

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

² Concentrations in runoff sediment

When comparing the mean concentrations for the northbound and southbound lanes, it appears that the southbound lanes had a lower level of contamination. When combined with the higher total mass on the southbound lanes, the conclusion that the less-polluted construction debris had a “dilution” effect on the road deposited sediment was well-supported.

3.2 Effects of Street Sweeping on Road Deposited Sediment

3.2.1 Effects of street sweeping on total mass and particle size

The total mass of solids collected over the dry test area (20 m x 4 m = 80 m²), was used to estimate the mass per curb kilometre which was available to collect from the road. In

this case, it was calculated as mass collected over the entire test area divided by the number of linear curb metres (20 m for this site). In the figures which follow, the results fall under the categories of old regenerative air (ORA), conventional mechanical (CM) and the new regenerative air (NRA). For the NRA, two distinct machines were used: one in 2005 was an older model and the updated (factory new) model was used in 2006. The 2005 and 2006 NRA categories are further sub-divided into northbound and southbound sites where appropriate.

The effectiveness of street sweeping at removing dry road deposited sediment (RDS) 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 ($M_{\text{unswept}} - M_{\text{swept}}$), the higher the sweeping efficiency. The mass per curb kilometre was calculated based on the total mass collected over a 4 m wide curb lane (by 20 m in length). If the width of the curb lane was smaller or larger, or the whole road width had been used, these values would be different. They are primarily used in the comparison between unswept and swept test sites. 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. The mean mass removed ($M_{\text{unswept}} - M_{\text{swept}}$) was 104 kg/curb km in 2005 (67% efficiency) and 163 kg/curb km (71% efficiency) in 2006. The old regenerative air sweeper, which was tested on the northbound lanes only, showed no improvement. The sweeper NRA was only able to achieve the 71% efficiency on the southbound lanes; the northbound lanes showed essentially no change in the total mass of solids using the same sweeper. The new regenerative air sweeper appeared to be capable of removing solids down to a certain "background" (residual) level (approximately 25-50 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 sweeping was particularly effective on streets with high solids accumulations; thus, to increase the effectiveness of street sweeping operations in pollutant source control, sweeping should occur more frequently on such streets.

Figure 3.12 shows the comparison of pre- and post-swept sites for total road deposited solids, for all sites and all years. It indicates that the lowest mass of road deposited sediment residue after sweeping was approximately 20 kg/curb km. It is evident from the scatter on the plot that a great deal of variation was experienced during testing. This was partly due to the incorporation of two sites with quite different background (unswept) conditions and the application of three different sweeping technologies. The correlation coefficient between swept and unswept was found to be 0.3239 when incorporating data from all years and all sites. Even when analyzing just 2006 data, the correlation coefficient was only raised to 0.4025. The slope of the curve demonstrates that at lower starting RDS levels (<50 kg/curb km), only small removals were possible (~10%). At higher starting RDS levels (>300 kg/curb km), much greater efficiencies were possible

(70-80%). Data from 6 trials performed by Waschbusch (2003) showed a much higher correlation of 0.9105. The Enviro Whirl street sweeper they tested was capable of removing 50% of the RDS at 140 kg/cub km (the upper limit of their tests), whereas our new regenerative air sweeper was capable of removing 65% (mid-range for our tests). They experienced the same lower limit of about 28 kg/curb km (100 lb/curb mile), beyond which they noticed no improvement in RDS levels.

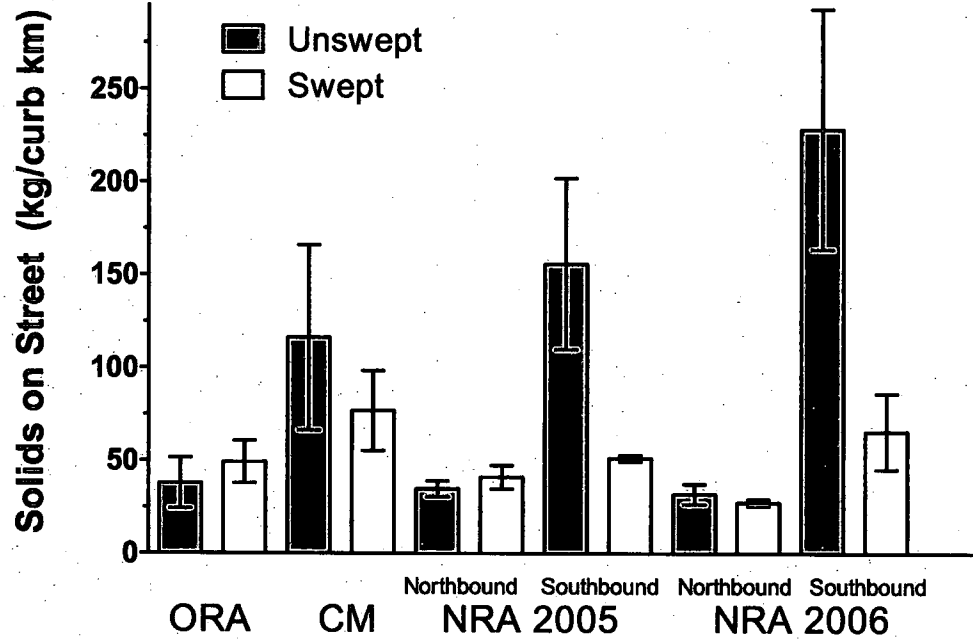


Figure 3.11: Total mass of solids (RDS) collected at swept and unswept sites

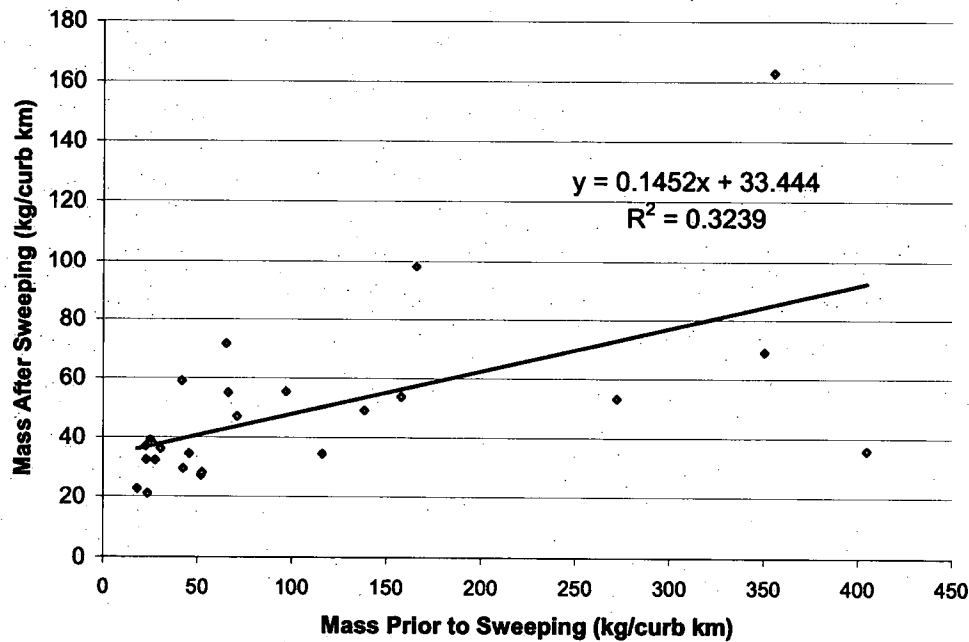


Figure 3.12: Mass of RDS before sweeping plotted against mass of RDS after sweeping (2004-2006 data)

Although the overall removal of solids from the road was an important factor in determining how effective street sweeping was, the removal of different size fractions were also of particular interest. Figure 3.13 shows the mass of gravel (calculated as the fraction of gravel x total mass collected from the street surface) on the street surfaces before and after sweeping for all three sweepers. It can be seen that although the southbound lane control site (conventional mechanical unswept and new regenerative air southbound unswept) 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 did not appear to be efficient at removing the gravel. This would suggest that the old regenerative sweeper was not able to produce sufficient lift to remove the gravel-sized particles from the street surface.

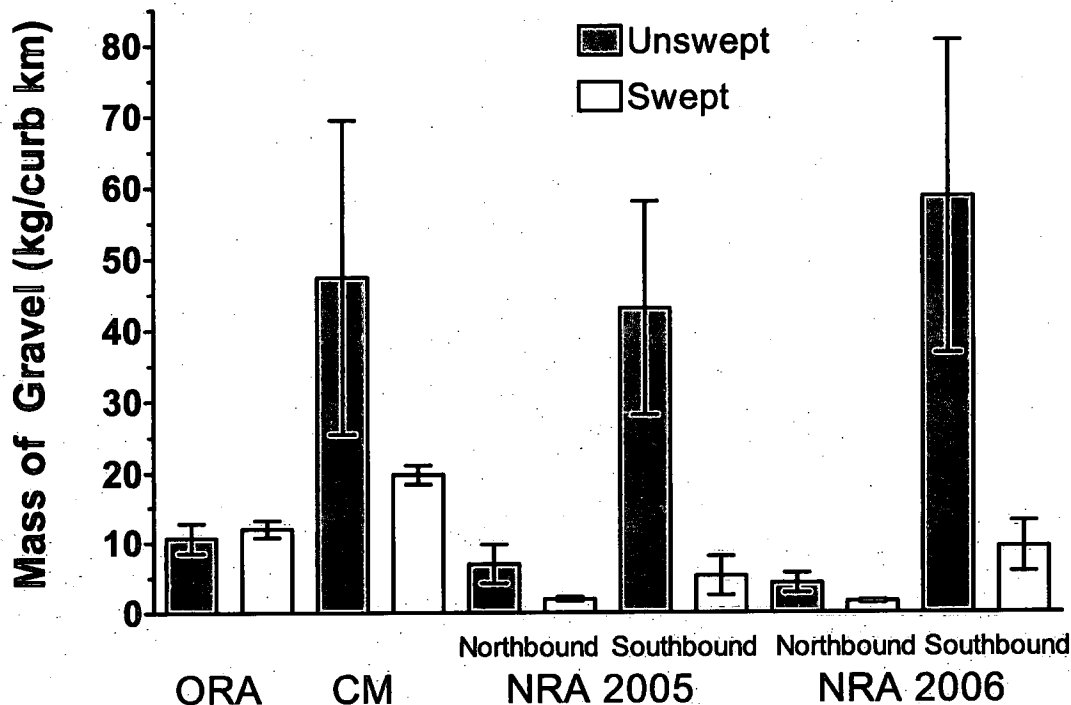


Figure 3.13: Total mass of gravel at swept and unswept sites

Sand is a major component of all road deposited sediment (Pitt et al., 2004), so the efficiency of street sweeping to remove 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). Once again, on the northbound lanes, there appeared to be no removal, but southbound lanes showed some improvement, which strengthened the argument that the sweepers may only be able to pick up material from the street down to some "background" level (the limit of the ability of the street sweeping equipment under those particular field conditions).

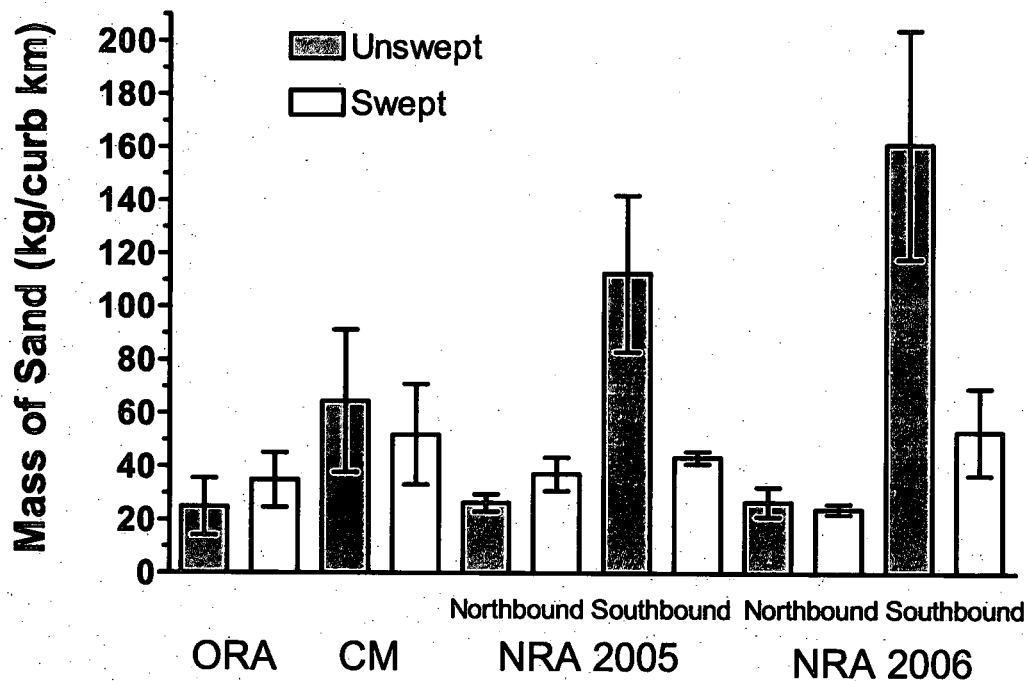


Figure 3.14: Total mass of sand at swept and unswept sites

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 demonstrated an ability to remove 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. This may again provide further evidence which demonstrates that a limit exists 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.

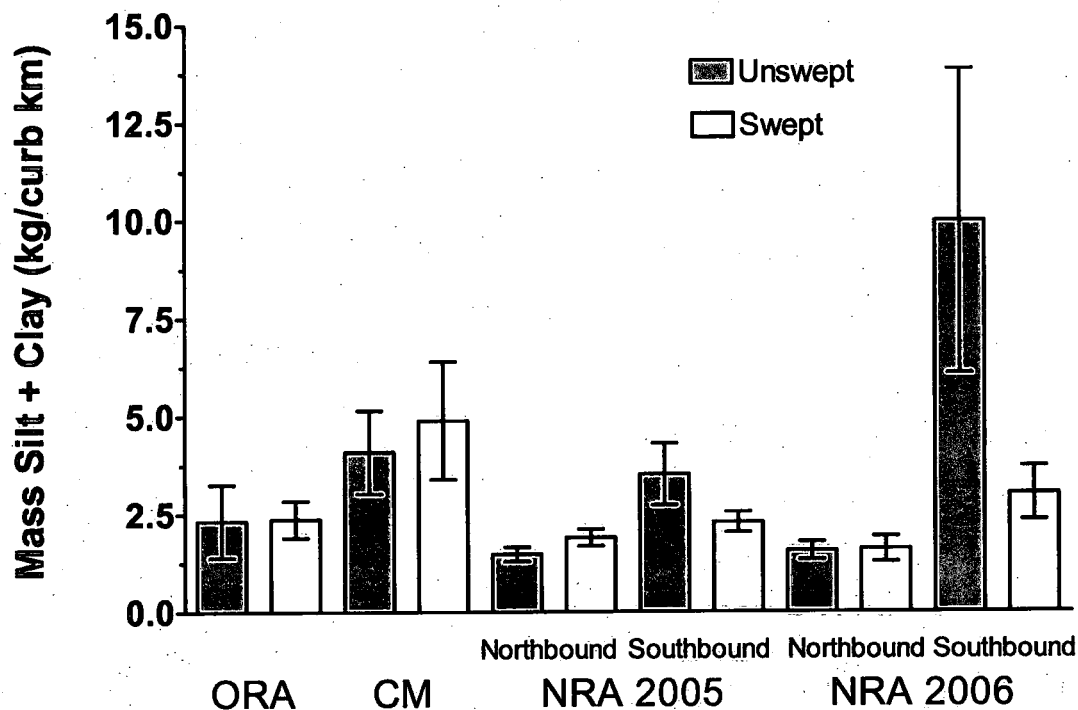


Figure 3.15: Total mass of silt + clay at swept and unswept sites

It was expected that street sweeping 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 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). It is important to note that even though the reduction in mean particle size was over 50% for this sweeper, it still left solids on the road surface which had a mean particle size of over 400 μm .

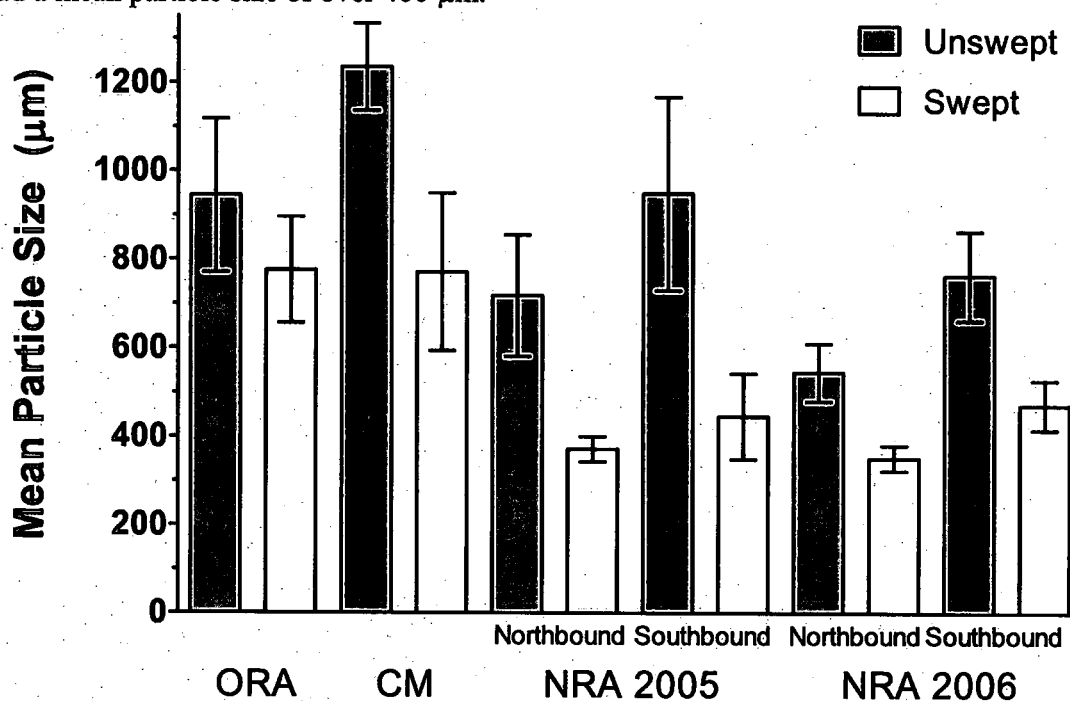


Figure 3.16: Changes in mean particle size

3.2.2 Effects of street sweeping on sediment chemistry

Street sweeping was also evaluated based on the ability to remove contaminants associated with road deposited sediment. The permanent removal of these materials from the road surface is critical to the effectiveness of street sweeping for the purpose of source control. In order to estimate the total mass of a particular pollutant which was present on the road surface, the pollutant masses associated with each fraction were added together. The mass of pollutant associated with a particular fraction was determined by multiplying the concentration of the constituent in each fraction (i.e., the concentration in the $< 64 \mu\text{m}$ and $64\text{-}2000 \mu\text{m}$) by the mass of road deposited sediment with that particle size fraction.

Figure 3.17 shows the relative differences between swept and unswept sites for total organic carbon (TOC). No change was noted for the majority of test cases, except for the southbound lanes in 2005 and 2006. Both new regenerative air sweepers were able to show significant removals of elevated levels of TOC. In all cases, levels were reduced to a background of between 1 and 3 kg TOC/curb km. The mean total mass of TOC was particularly high along the southbound lanes in 2006. In fact the concentration of TOC in the sediment was similar for all samples collected, but the total mass of the sediment in the southbound lanes increased significantly in both July and November over previous years. Some of the additional TOC in November could be explained by the presence of fall leaf litter.

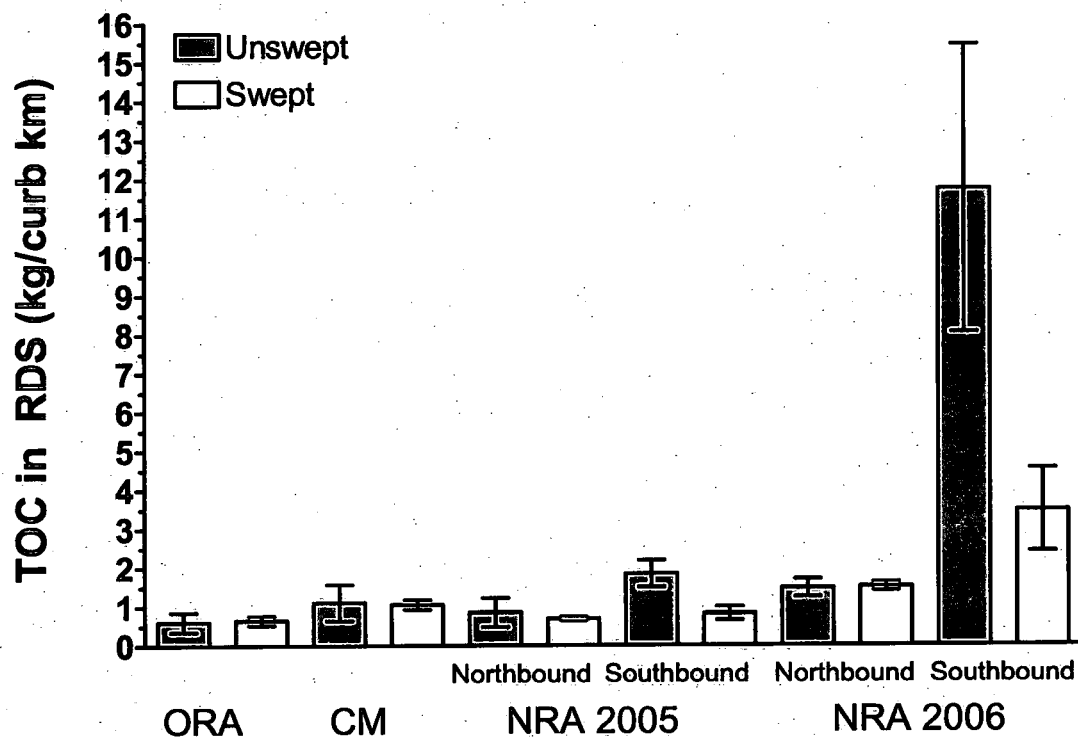


Figure 3.17: Total mass of TOC in RDS

Figure 3.18 shows the effect of street sweeping on total Kjeldahl nitrogen (TKN). Most cases showed no change between unswept and swept sites, however in 2005, the northbound lanes showed a significant increase, while at the same time, the southbound lanes (which had a higher loading), showed a significant decrease. Background levels were much more difficult to determine for TKN – they ranged from 10 to 40 g TKN/curb km.

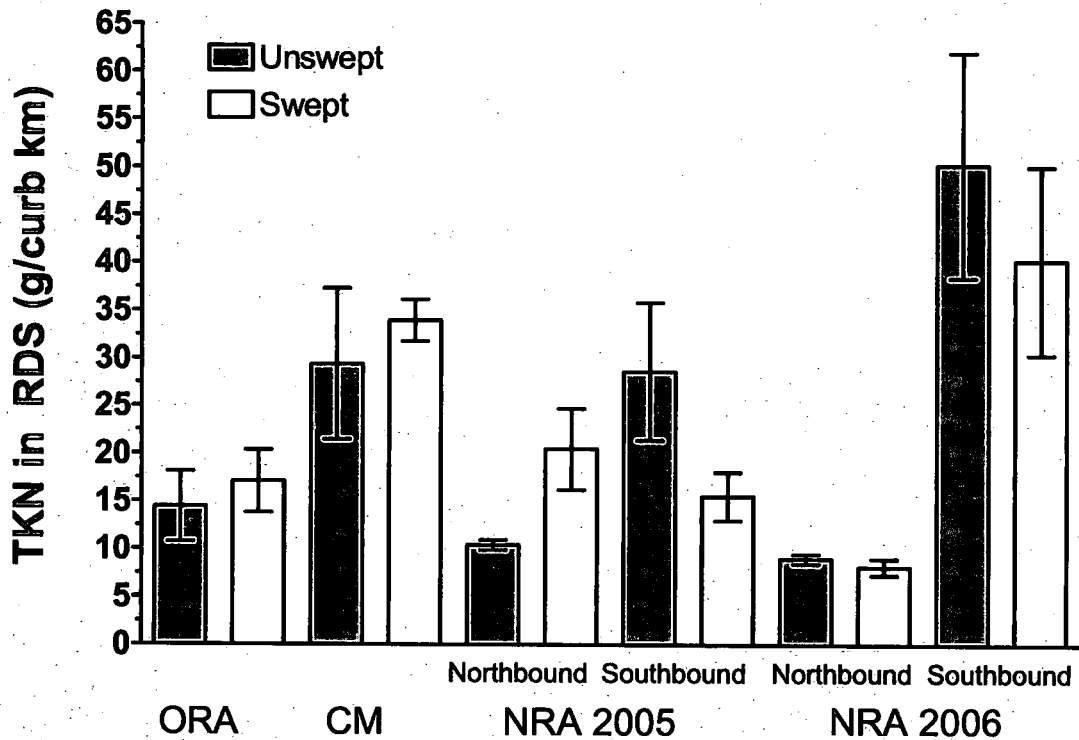


Figure 3.18: Total mass of TKN in RDS

Results for the effectiveness of street sweeping on the total phosphorus (TP) loadings are shown in Figure 3.19. Most cases again showed little change between the unswept and swept sites. The new regenerative air machines demonstrated an ability to remove higher levels of TP from the road surface (southbound lanes 2005 and 2006), but also from the northbound lanes in 2006, where levels were close to background (between 10 and 30 g TP/curb km).

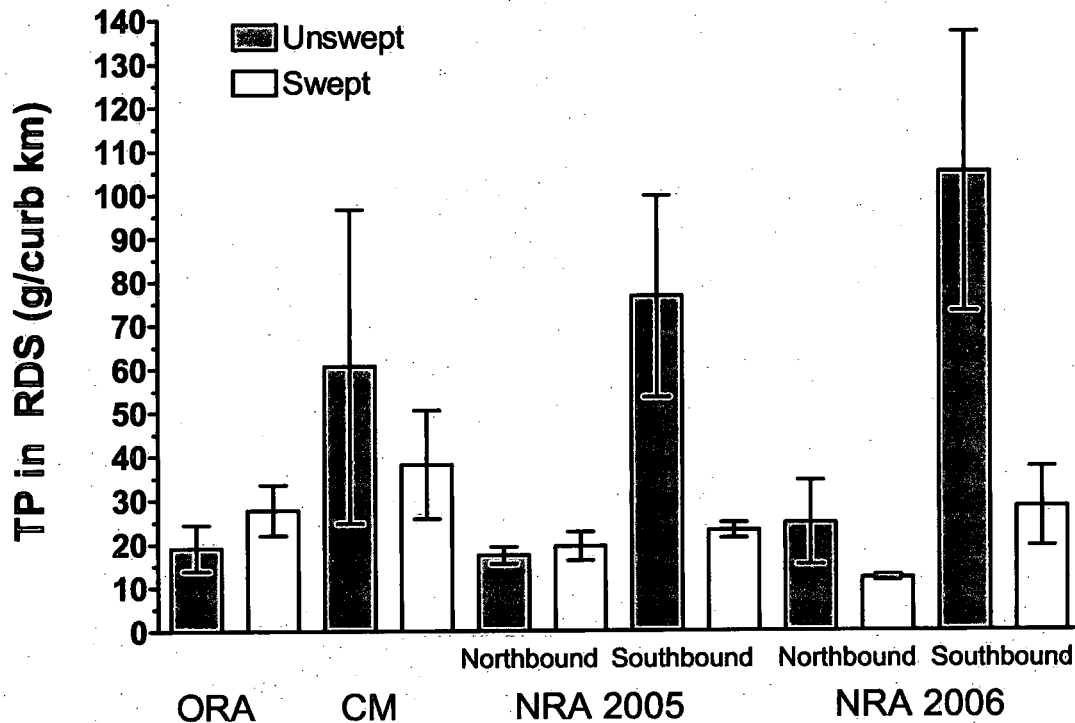


Figure 3.19: Total mass of TP in RDS

Three key metals were analyzed in a similar fashion to the nutrient data. Figure 3.20 shows the effect of street sweeping on copper in RDS. No significant change in the levels of Cu in RDS was found after sweeping. Some post-sweeping trends showed a decrease (particularly on the southbound 2005 and 2006 data), but these results were not significant. Most levels remained in the “background” range of 5-8 g Cu/curb km.

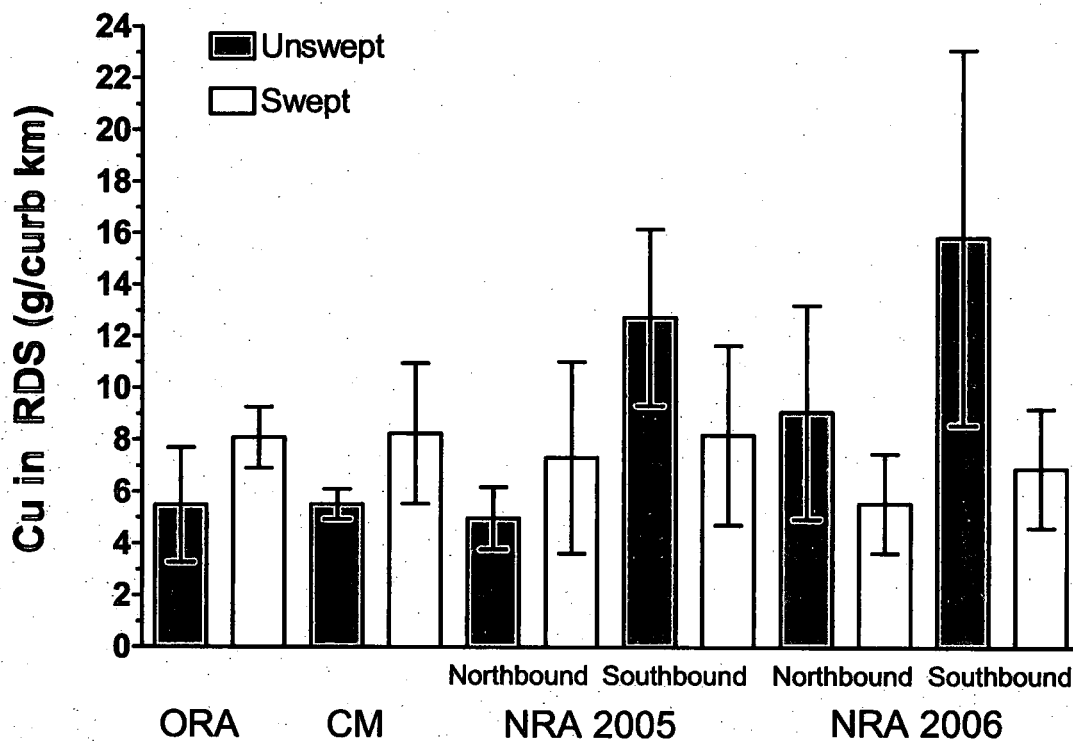


Figure 3.20: Total mass of Cu in RDS

Lead was well-reduced by the regenerative air sweepers (Figure 3.21), however, while the data show significant decreases for the ORA (northbound lanes), NRA 2005 southbound and the NRA 2006 southbound, the northbound lanes in 2005 and 2006 show a tendency towards increasing levels of lead. The conventional mechanical sweeper also showed some tendency towards reducing lead levels, but due to the variation in the data and limited number of data points (n=2) it was not a significant result. All of the swept sites were similar in lead levels, indicating a background concentration of 2-3 g Pb/curb km.

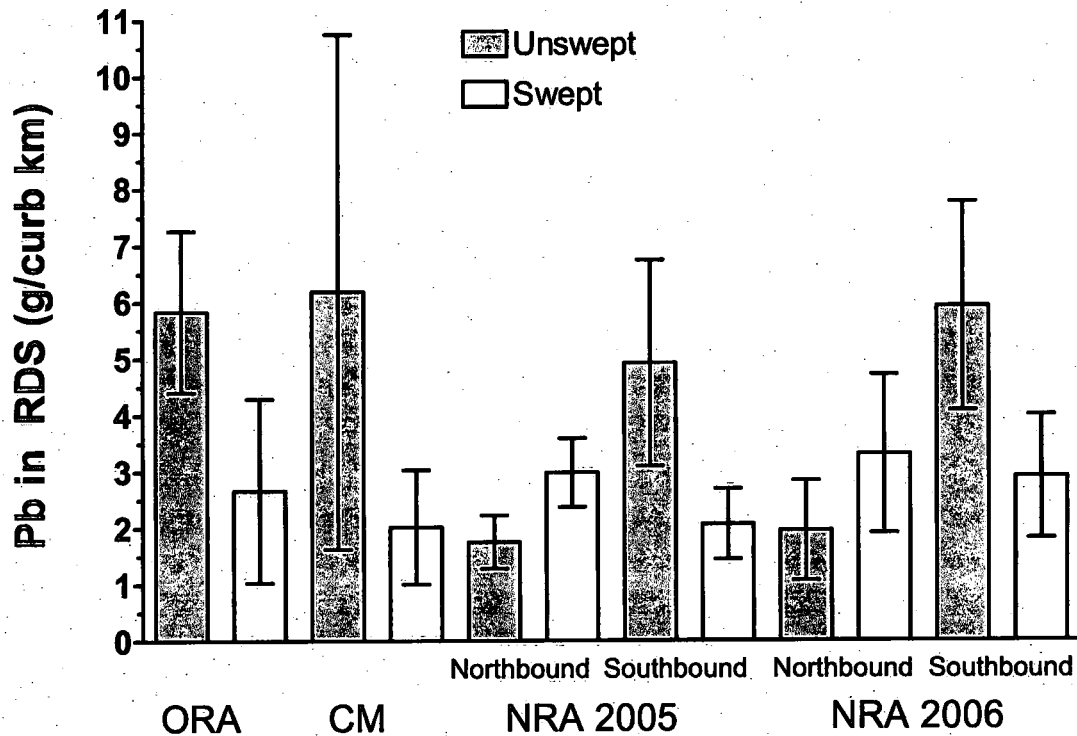


Figure 3.21: Total mass of Pb in RDS

Zinc appeared to be well-reduced by sweeping, particularly in 2005 and 2006, along the southbound lanes (Figure 3.22). The conventional mechanical sweeper (CM) showed some improvement in the levels of Zn on the road, but this was not a significant result. Northbound lanes showed no effect of sweeping and background levels of Zn in the RDS appear to be 7-15 g Zn/curb km.

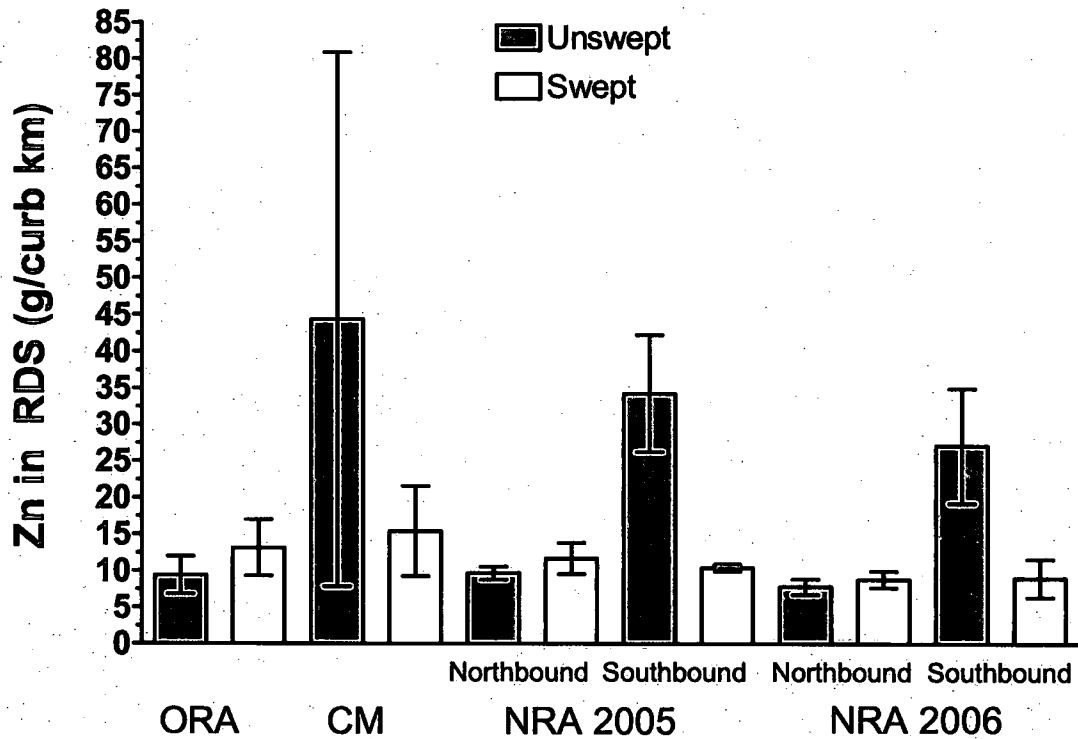


Figure 3.22: Total mass of Zn in RDS

The three commonly occurring PAHs (phenanthrene, fluoranthene and pyrene) were selected as representative PAHs for detailed analyses. The results show strong similarities between all three PAHs, but the phenanthrene results differ slightly from the fluoranthene and pyrene results. Figure 3.23 shows the changes in phenanthrene in RDS after sweeping. Only southbound lanes in 2005 and 2006 (NRA sweeper) showed significant reductions between swept and unswept. No change was noted for other sweepers or for the northbound lanes in 2005 and 2006. Background levels appeared to be 10-25 mg Phenanthrene/curb km.

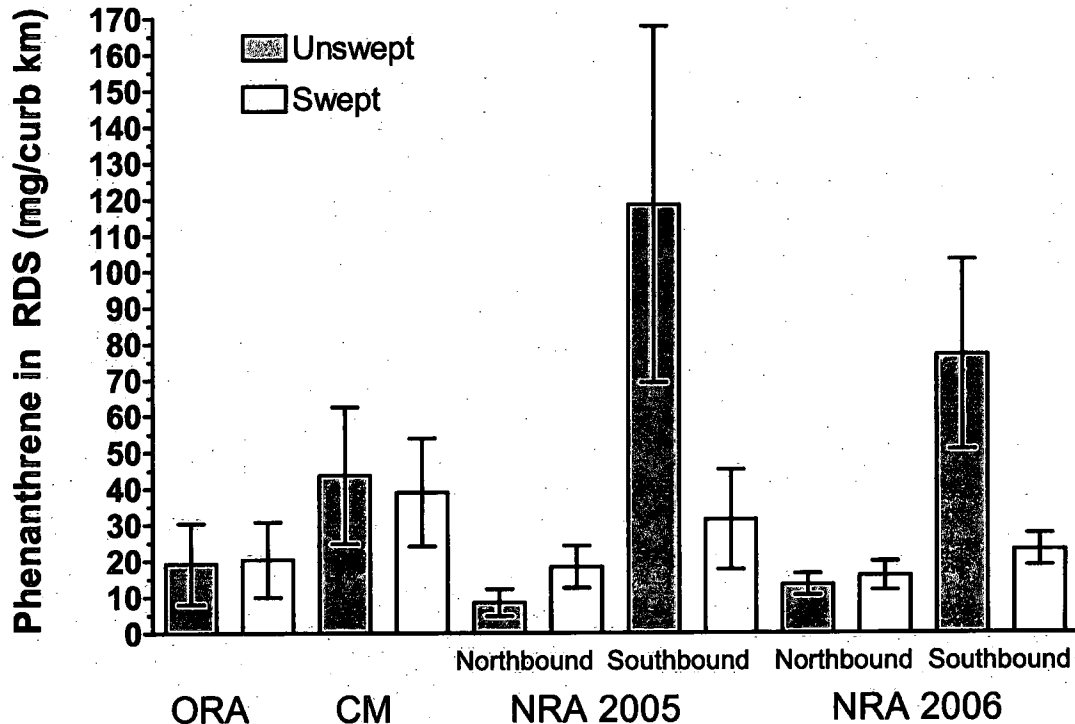


Figure 3.23: Total mass of Phenanthrene in RDS

The fluoranthene data (Figure 3.24) and pyrene data (Figure 3.25) are quite similar to the phenanthrene data, with the exception that they show evidence of some contamination by the conventional mechanical (CM) sweeper. The southbound lanes in both 2005 and 2006 show significant reductions in the total mass of organic contaminants left on the road after sweeping. Conversely, the northbound lanes in 2005 show significant (though small) increases. The residual mass of RDS for each of the organic compounds was found to be between 20 and 40 mg/curb km.

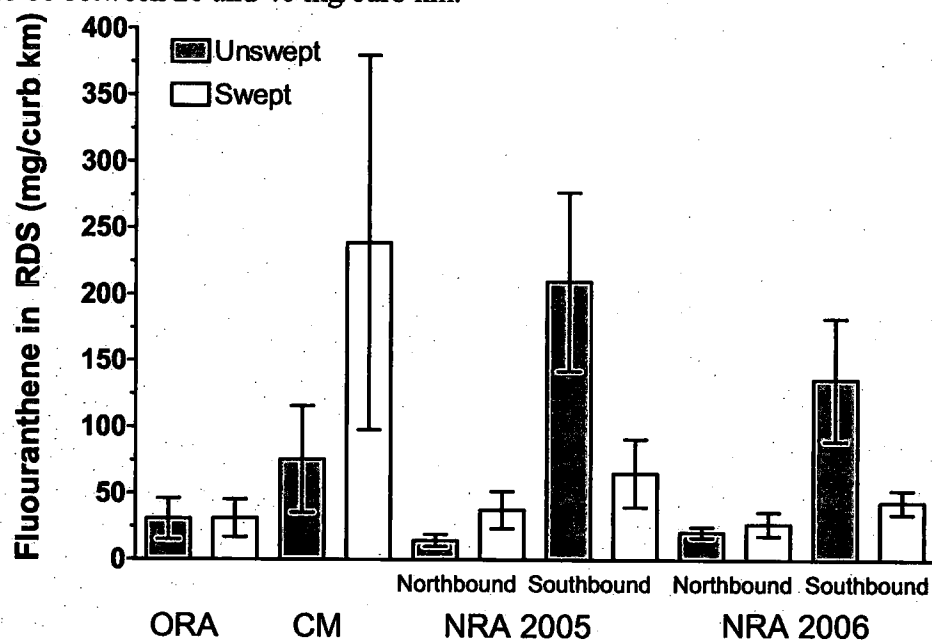


Figure 3.24: Total mass of Fluoranthene in RDS

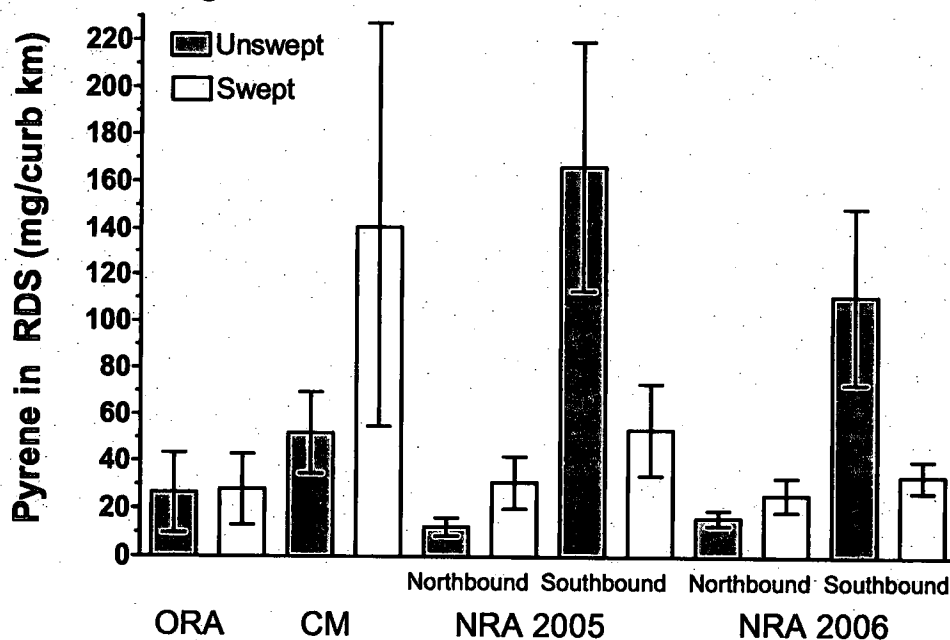


Figure 3.25: Total mass of Pyrene in RDS

3.3 Effects of Street Sweeping on Simulated Runoff

3.3.1 Effects of street sweeping on runoff chemistry

When using street sweeping as a method of source control, one of the main expectations was to reduce the loading of pollutants which could be transported to the receiving waters during wet-weather events. An evaluation of the effectiveness of street sweeping to influence the amount of sediment which was transported to the receiving waters was conducted for the test catchments by comparing the simulated runoff from swept and unswept sites. Since TSS measurements were based on the volume of water used to wash off the catchment, the total mass of solids washed off the catchment was selected as a more accurate indicator. 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 assumed that TSS values accounted for all solids in the catchbasin; some larger solids which settle out quickly may not have been included in this estimate. This value was then used to extrapolate to the mass per curb kilometre.

Figure 3.26 shows that the solids washed off were relatively unchanged by sweeping, regardless of method or location. The higher (dry) road deposited sediment loads in 2005 and 2006 contributed to the higher observed solids washed off on the southbound lanes. In 2005, levels were still similar to previous years, but 2006 levels appeared to be much higher. 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. Even when certain outlier values were excluded (dates where high TSS values in swept sites corresponded with field observations of “dirty sweepers”), there was no difference between the swept and unswept sites. Figure 3.26 shows values with all data points included. The change in washoff methods between 2004 and 2005 (rain shower hose nozzle and light-pressure water broom) produced very similar results. All three years showed that the same size range of particles were being washed off the road surface and into the catchbasin insert (approximately 90% of solids in runoff were $< 50 \mu\text{m}$), with mean particle sizes of $10.0 \mu\text{m}$ (2004), $11.7 \mu\text{m}$ (2005) and $10.21 \mu\text{m}$ (2006). This would suggest that mostly the silt and clay material ($< 64 \mu\text{m}$) was washed off under the test conditions and considerably larger volume / higher intensity storms would be required to move the larger particles. The complete summary of water chemistry results for the simulated runoff is presented in Appendix C.

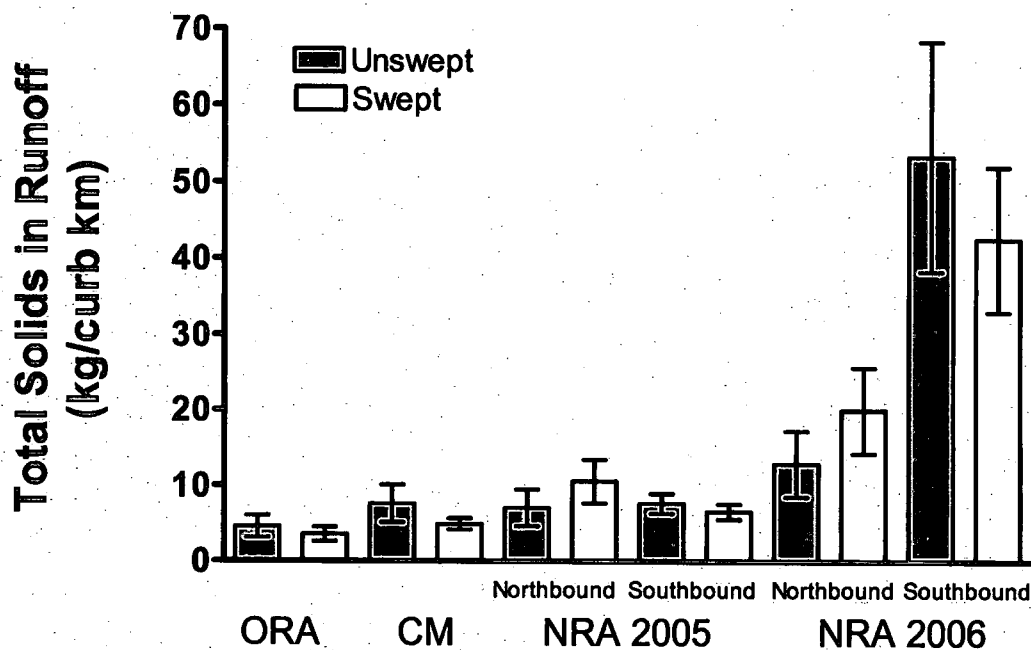


Figure 3.26: Changes in total solids washed off

Since none of the sweepers were able to reduce the total solids washed off the road surface, it was expected that there would also be relatively little change in the chemistry (metals and PAHs) associated with this runoff, however, this was not always the case.

In order to compare the influence of sweeping on the amount of dissolved material in the simulated runoff, the total mass of the pollutant was estimated from the product of the concentration and the volume of water used to create the runoff. Figure 3.27 shows the effectiveness of sweeping on dissolved Cu. Although some reductions were noted (e.g., conventional mechanical), Cu was relatively unchanged by sweeping and a background level of about 0.1 – 0.15 g Cu/curb km was observed. Unfortunately, most dissolved Pb levels were below detection and no data could be presented for comparison. Figure 3.28 shows the effectiveness of sweeping on dissolved Zn. Dissolved Zn was only reduced by the regenerative air sweepers, (although not for southbound lanes in 2006) and a background level of about 0.1 – 0.2 g Zn/curb km was observed. 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).

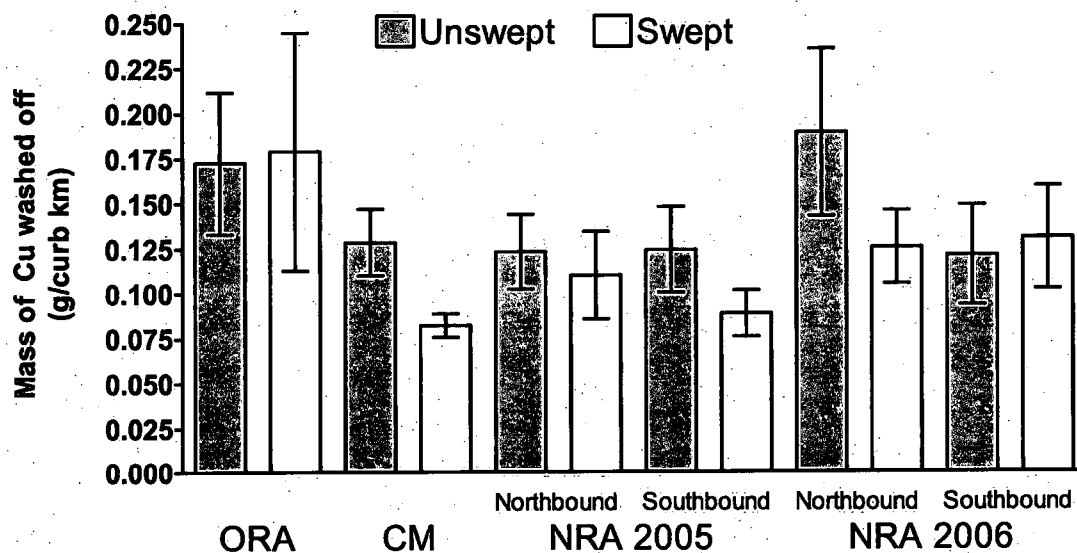


Figure 3.27: Changes in dissolved copper in runoff

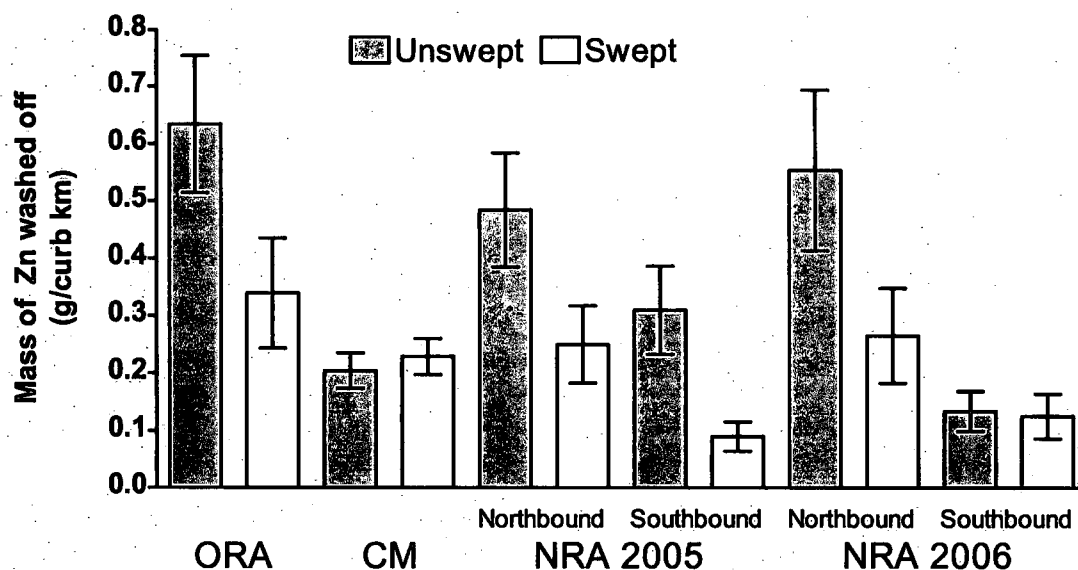


Figure 3.28: Changes in dissolved zinc in runoff

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), as these are commonly recognized as originating from urban pollution sources, including fuel oil and products of combustion (Takada et al., 1990). Figure 3.29 shows the effect of street sweeping on phenanthrene, Figure 3.30 shows the effect of street sweeping on fluoranthene and Figure 3.31 shows the effect street sweeping 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 most cases, there were a few instances (NRA northbound 2005) where swept sites appeared to have (in some cases significantly) higher PAH concentrations on average. This may reflect the influence of sources of PAH contamination tracked in from other sources.

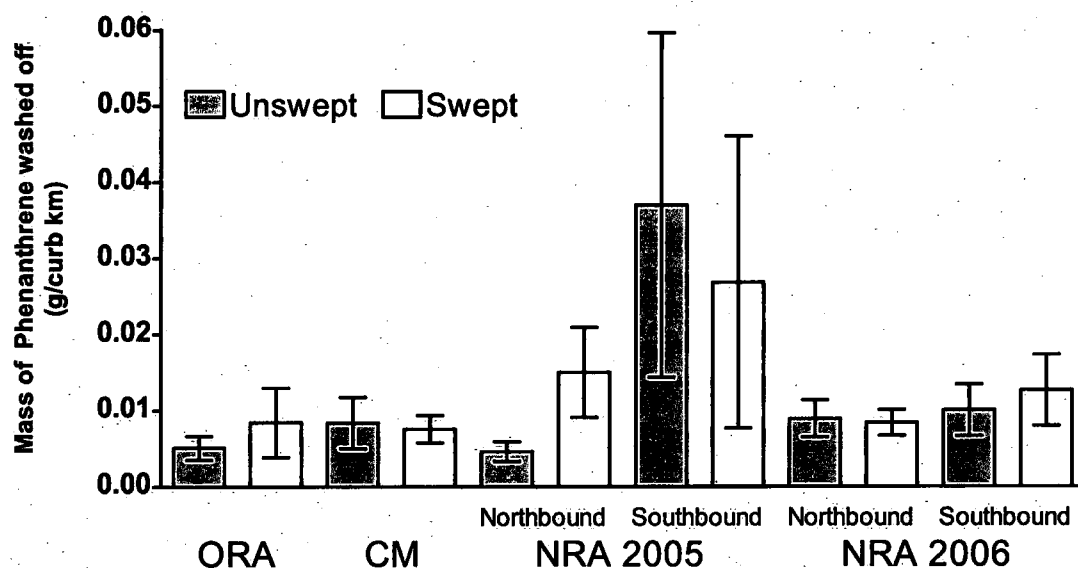


Figure 3.29: Changes in phenanthrene concentrations

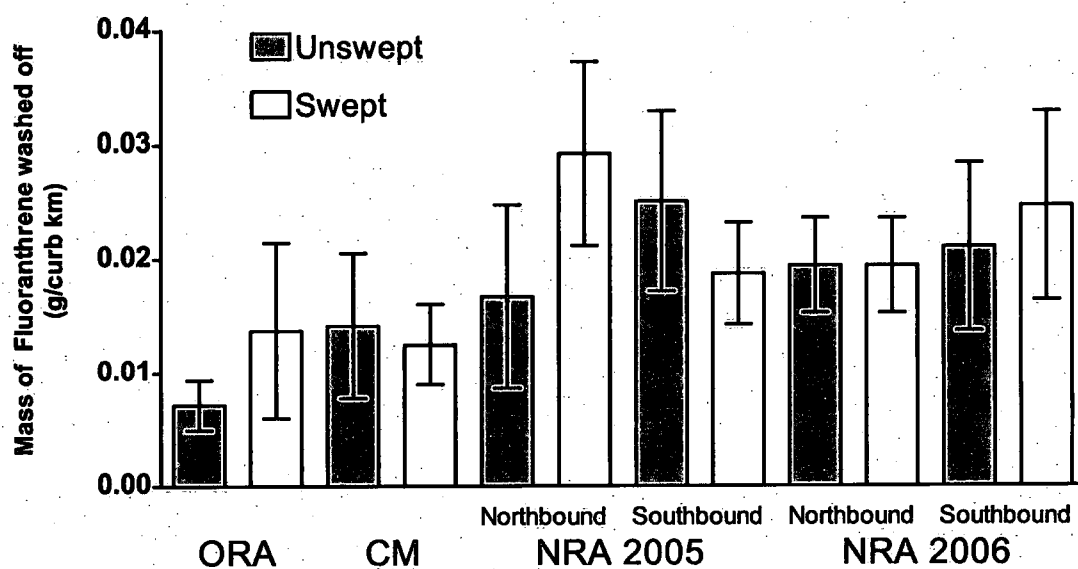


Figure 3.30: Changes in fluoranthene concentrations

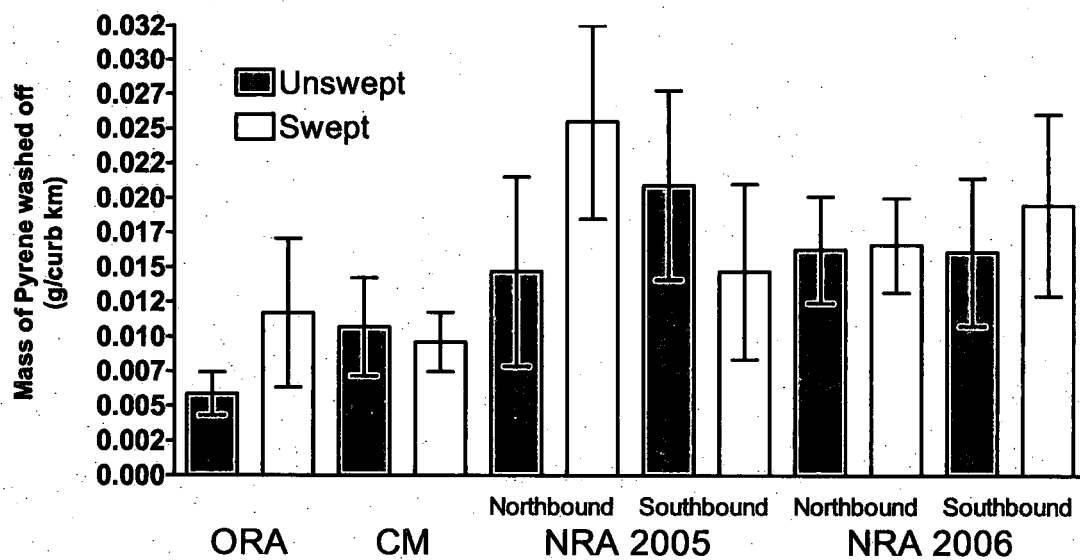


Figure 3.31: Changes in pyrene concentrations

3.3.2 Effects of street sweeping 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 3.32 shows the impact that street sweeping had on the toxicity of the simulated runoff. Rainbow trout toxicity results were highly variable for all sites. During the 2005 testing, very little toxicity was encountered (almost all sites were non-toxic), but in other years, toxicity was minor. In Figure 3.32, the toxicity was defined by the lethal concentration required to kill 50% of the population and was expressed as LC50. When the LC50 is 100% (or greater), it was an indication of no toxicity. As the LC50 value decreased, the severity of the toxicity increased. For comparison purposes, a "fail" in this test was 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 periods. Although on occasion, some paired tests showed a slight reduction of toxicity, none of the tests demonstrated a clear ability to reduce the toxicity of the simulated runoff.

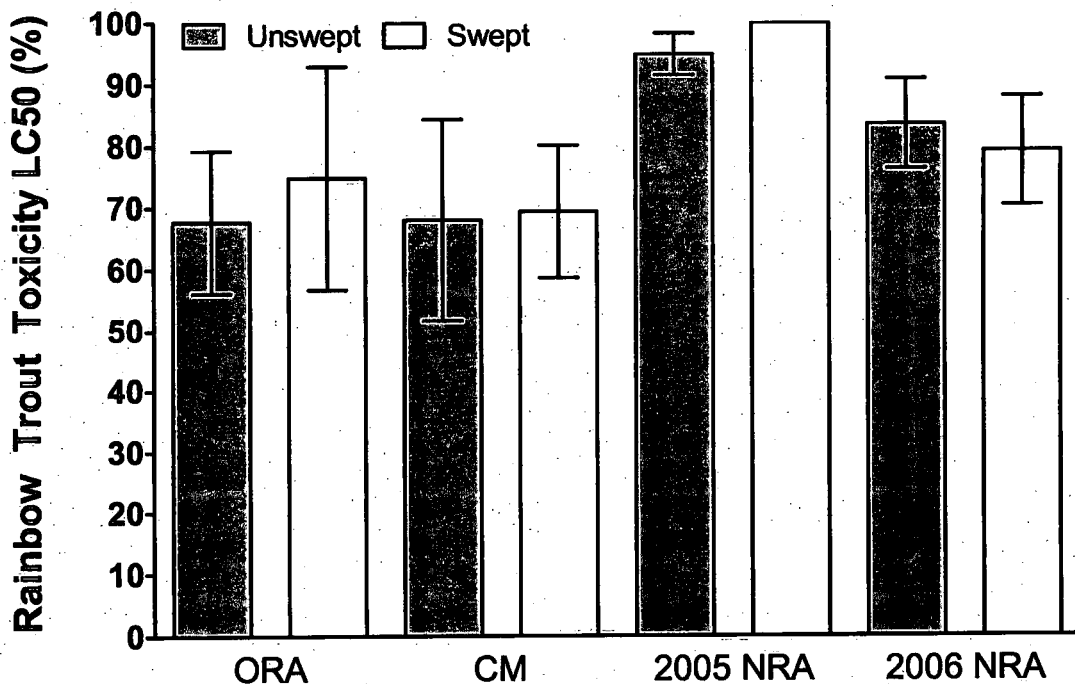


Figure 3.32: Changes in toxicity to Rainbow trout (Note: 100% is non-toxic)

It was interesting to note that the 96-hour acute *Daphnia magna* LC50 test did not show any evidence of toxicity. All of the test results (2004-2006) showed 100% survival.

The bioluminescent bacteria (*Photobacterium phosphoreum*) used in the Microtox™ test reduce their light output as the level of toxicity in the sample increases. 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. Only one of the samples (SBUS 2004 at 10%) showed an EC50 value below 40% (acute toxicity is confirmed at EC50 < 40%) and therefore most of the samples were not considered to be acutely toxic (EC50 < 10%). In order for all samples collected to be compared, the sub-lethal “percent effect” value, which could be calculated for all cases, was used instead. Percent effect measures directly the impact of the raw sample on total light output by the test organisms. On this scale, zero percent effect would indicate no impact (no reduction in light output relative to controls); as the percent effect climbs, so does the toxicity. Figure 3.33 shows the percent effect for Microtox™ 15-minute acute test samples. In most cases, the mean at the swept sites was lower than the unswept, indicating a reduction in toxicity. The only case where a significant reduction was apparent was for the old regenerative air machine (ORA), northbound lanes in 2004. The most toxic samples were found in the southbound unswept runoff in 2006, but the corresponding swept site runoff showed a similar level of toxicity. Although both the conventional mechanical and the new regenerative air sweepers did show trends (on average) towards reducing the toxicity, none of these results could be considered significant.

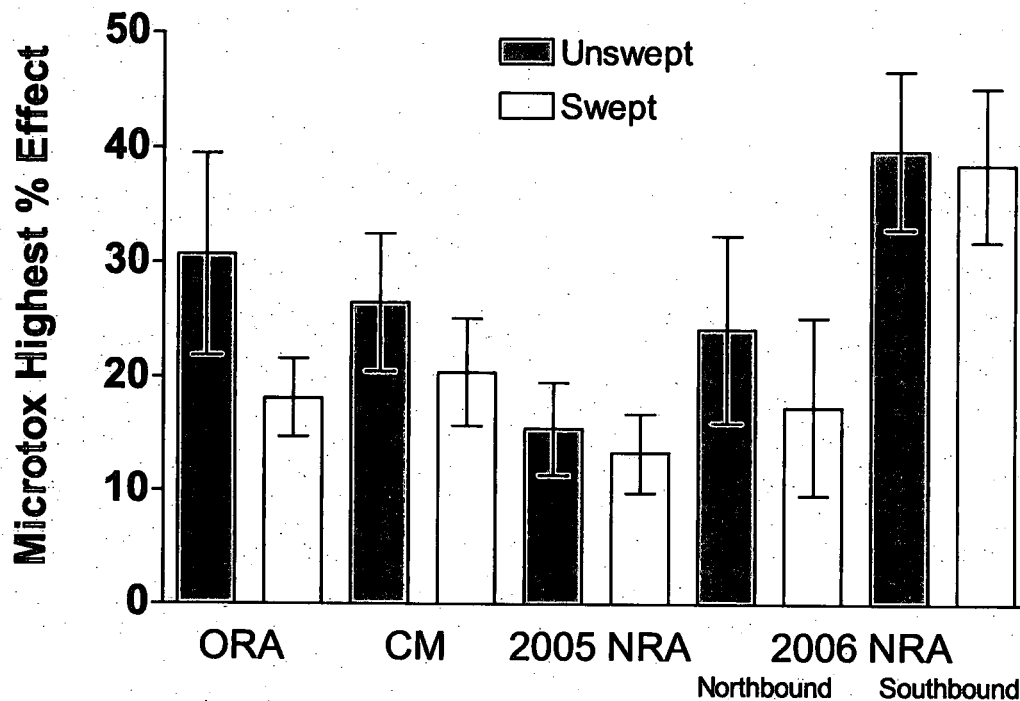


Figure 3.33: Changes in Microtox™ 15-minute % effect (Note: % effect is the reduction in light output and therefore a greater % effect is more toxic)

3.4 Summary of Results

A brief summary of the findings follow, which is meant to highlight important data from the study. This study did not have the objective of comparing sweepers, but to determine if street sweeping practices in general could support the use of street sweeping as a method of source control.

- In the composition of road deposited sediment samples, gravel ranged from 4 to 42%; sand from 54 to 91%; silt and clay from 2 to 6%.
- Mean particle size of the sediment samples from unswept sites was 544 μm northbound and 761 μm southbound.
- Sediment accumulation rates of 9 to 22 kg/curb km/d were similar to literature values (again, construction was expected to influence the southbound lanes).
- Mean sediment loads were on the order of 35 (NBUS) to 170 (SBUS) kg/curb km.

In simulated runoff (wash off) samples:

- Mean particle size for simulated runoff into the catchbasin was 10.4 μm 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 15.4 kg/curb km; or just 15% 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 simulated wash off experiments). It is likely that the road deposited sediment consolidates as it ages on the road surface, making it more resistant to wash off.
- The highest concentrations of contaminants (per unit mass) were found in the <64 μm 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 (approximately 50 kg/curb km). This was only possible on the southbound lanes, where loadings were much higher. It was also better at removal of (specifically) gravel (up to 88%) and sand (up to 62%). Once above a certain threshold, silt + clay removal (up to 35%) 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).
- In road deposited sediment, TOC, TP, Pb, Zn, phenanthrene, fluoranthene and pyrene could be reduced by sweeping with the NRA sweepers, but the effect was much greater on the southbound lanes where loadings were higher.
- No sweeper demonstrated an ability to reduce solids washed off by simulated runoff. This may support the hypothesis that the sweepers can only pick up so much material; below a certain level of road deposited sediment, sweepers may be

ineffective, leaving the fine residual material (up to 50 kg/curb km) 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 in simulated runoff was reduced by the regenerative air sweepers, but not by the conventional mechanical sweeper. Dissolved copper was unchanged.
- 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 vehicles / 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 "diluting" the toxic sediment. 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 typically less contaminated than sediment from 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). Although some researchers have found that road deposited sediments accumulated at a predictable rate (Pitt et al., 2004), Herngren et al. (2006) found the rate of accumulation to be unpredictable. In this study (particularly for southbound lanes), the rate of accumulation was quite variable and did not appear to be governed solely by time. The lack of consistency and extreme variation in the swept and unswept conditions at our field site made comparisons between swept and unswept sampling areas 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 54% or greater) and low amounts of silt + clay (< 6%) on the southbound lanes meant that the overall performance of the sweepers was mainly based upon their ability to pick up sand and gravel, rather than fine particles.

The solids and associated pollutants which were deposited on the road surface then acted as source material which could be washed off from urban streets. The chemical characterization of this material was important for determining the potential pollutant loads which could be washed off by stormwater to downstream treatment facilities and receiving water bodies. The intensity and duration of storm events would affect the total mass and size of particles washed off and carried into the receiving environment (Novotny, 2003). 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. If less material is available for washoff (including the silt + clay fractions), there is the potential that runoff quality may be improved by street sweeping.

One of the major difficulties encountered in street sweeping studies was the scale at which most of them have been performed (catchment level) and the fact that they rely on natural rainfall for stormwater runoff generation. It was apparent that the ability to control runoff generation was a key factor in reducing the extreme variation in these results. Both Tiefenthaler et al. (2001) and Pitt et al. (2004) elected to create their own rainfall and use small-scale catchments (and parking lots) to avoid complications with such large-scale studies and natural storm events. In this study, a similar approach was adopted, but rainfall was generated in a different way. The methods used to simulate

runoff in this study were able to reproduce 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 (approximately 10 μm mean particle size), 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 Sweeping on Road Deposited Sediment

A reduction in the overall mass of road deposited sediment could only be achieved by the new regenerative air sweepers. None of the other sweepers could achieve a significant reduction in this parameter. Without a reduction of road deposited sediment loads, it was unlikely that any corresponding improvements in runoff quality would occur. However, this 67 – 71% removal (2005-2006 NRA data) was only achieved along the southbound lanes (with higher accumulations of material), whereas the northbound lanes actually showed no change in the amount of road deposited sediment. It appears possible that for street 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, type of material being picked up and sweeper cleanliness could be controlled, these statistics would likely improve. The range of 25 – 50 kg/curb km determined by this study as the "background" level of road deposited sediment after sweeping was higher than similar findings in studies by Waschbusch (2003) (4 kg/curb km) and Minton et al. (1998) (3 kg/curb km). Pitt et al. (2004) noted that below 100 lbs/curb mile (28 kg/curb km), the amount of material picked up was negligible. In these studies, 50% removal was achieved once loadings approached 500 lbs/curb mile (140 kg/curb km). The sweepers used in this study achieved 50% removal at 110 kg/curb km.

When analyzing the results of the mass of gravel, sand and silt + clay particles removed from the road surface, the new regenerative air sweeper was able to provide a consistent reduction in the quantities of all of these particles. The low loadings on the northbound lanes meant that little improvement in the level of road deposited sediment was seen for anything except gravel. Particle size in general was also best reduced 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_{10} and $\text{PM}_{2.5}$ specifications) along with improved street sweeping techniques and practices, reductions of this background level should be achievable (to 10 kg/curb km or less) to the point

where there would be much less material (including the fraction $< 64 \mu\text{m}$) available to be washed off.

4.3 Effects of Street Sweeping on the Quality of Simulated Runoff

In this study, single catchbasin drainage areas (80 m^2) were compared using simulated runoff in an effort to provide similar conditions for each test, however the results from runoff chemistry analyses were still 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. This was very similar to the variability (both positive and negative removal efficiencies) encountered in earlier studies by other researchers who surmised that those solids left behind after sweeping were fine enough that they were now more easily washed off (Sartor and Boyd, 1984) or that the solids removed provided a protective covering for the fine material, which now exposed, was more easily washed off the surface. Similarly, the total metal and PAH chemistry of swept and unswept sites for these sites was found to be highly variable and significant differences were not noted. This suggests that the sweeping practices used in this study did not alter the pollutant load susceptible to washoff to a large degree, but because it removed litter, sand and gravel which could cause vehicles to skid, it did improve the safety and aesthetics of the street. The fact that some parameters such as dissolved Pb and Zn (known toxicants) were reduced in the simulated runoff by the regenerative air machines, suggested that these sweepers could still have a beneficial effect on the total loads on the receiving environment. This is similar to findings in other studies (Taylor and Wong, 2002). Further work, under optimal conditions would be needed to confirm these findings.

The toxicity results for this study were low for a commercial area such as Markham Road, however, the traffic density (26,000 vehicles/day) may have been too low for toxic effects to occur. The complete absence 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 the sub-lethal “% 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, none of the results were significant at 95% confidence. Tiefenthaler et al. (2001) was able to use sea urchin fertilization, mysid survival and growth and Microtox in toxicity identification evaluations (TIEs) to demonstrate that Zn was a major factor in runoff toxicity for a commercial parking lot, but due to low toxicity at this site, such determinations were not possible.

Transfer of solids from other locations was found to be a potential problem in the operation of these sweepers. Other researchers (e.g., Waschbusch, 2003) encountered

similar difficulties in their studies. It was likely that the November 10, 2004 sweeping operation had a much higher level of contamination than on other test dates since the same street sweeper was also being used in nearby residential areas to clear up leaf debris at that time. This additional material was 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 and 2006 suggested that the transfer of solids from outside sources was no longer a problem during the tests.

5 CONCLUSIONS AND RECOMMENDATIONS

The new technology sweepers offer a greater potential for improvement over the older generation of sweepers they replace. The key to improving the effectiveness of such a source control measure is the way in which it is applied. In order to be more effective as a means of source control, sweeping with the most efficient sweepers available, as often as practical (and affordable), would be desirable. The sweepers should be clean and well maintained in order to operate at peak efficiency. Operators should 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. The costs associated with these requirements need to be factored in to long-term plans for wet-weather flow management.

The objective of this study was to assess the potential for street sweeping to improve stormwater runoff quality. 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 technology and less efficient sweepers in the earlier studies of street sweeping, a new approach was adopted for this study for assessing the environmental benefits of sweeping; both toxicity and chemistry were used to evaluate the changes in runoff from both swept and unswept (control) test areas. Within the limitations of this study and the realm of experimental uncertainties, the results indicated that the new regenerative air sweepers tested did provide some key benefits, including a reduction of the total mass of road deposited sediment (RDS) 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 the RDS after sweeping, but no environmental benefits were observed. The total mass of solids washed off test areas during generation of simulated runoff were unchanged by sweeping. No toxicity was noted for *Daphnia magna*, and only limited toxicity was evident for Rainbow trout and Microtox™. None of the sweepers demonstrated a (statistically) significant reduction of runoff toxicity, although swept sites were usually less toxic than the unswept ones. The test data showed only limited improvements in runoff quality for the simulated runoff from catchments which had been swept using regenerative air sweepers. The high-efficiency regenerative air sweepers may be more effective in trapping fine particles than older sweepers and as such to do not reduce local air quality as much as other machines. They still do not work

well enough to greatly improve the runoff quality. Improvements to dust capture methods (e.g., cowlings over gutter brooms, more efficient filters, flexible seals on vacuum pickup head etc.) to better accommodate the irregular surfaces encountered on real-world streets would be needed before capture efficiency of fine particles could be improved.

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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. From MOE – not allowed to submit samples after Thursday due to extreme load in lab
NOTE		Rain / drizzle (low level) all day for several days
Wednesday October 12, 2005	N	
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 B1 (continued): Road Deposited Sediment – Nutrient Chemistry

	Units	18-Jul-06								10-Aug-06							
		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)	%	8.1	5.2	7.1	5.5	6	5.2	5.6	4.5	6.9	4.3	7.1	4.4	6	5.7	6.7	4.2
TKN (as N)	mg/kg	1080	243	1060	290	634	249	594	242	N.M.	307	1030	258	1020	308	902	321
Total Phosphorus (as P)	mg/kg	813	354	775	679	770	427	842	461	N.M.	380	826	3330	728	372	787	475
Total Weight of solids	g	638.5		543.0		3238.0		7060.0		640.5		450.0		1103.0		1926.0	

	Units	22-Aug-06								28-Sep-06							
		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)	%	8.4	7.3	9	5.2	6.9	5.7	4.5	3.8	8	4.6	6.8	4.5	7.5	5.4	6.5	5.1
TKN (as N)	mg/kg	1540	423	1560	397	1200	441	1220	342	735	223	1060	336	493	167	490	155
Total Phosphorus (as P)	mg/kg	750	517	764	365	707	432	740	416	655	444	749	464	665	457	667	327
Total Weight of solids	g	447.5		353.0		685.0		903.5		415.0		464.0		1375.0		6992.5	

	Units	18-Oct-06								22-Nov-06							
		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)	%	8.3	5.1	8.2	4.5	7	4.7	6.9	5	5.4	6.3	7	3.2	5.5	4.5	7.1	5.9
TKN (as N)	mg/kg	837	255	590	170	673	238	570	213	616	177	658	190	508	159	426	169
Total Phosphorus (as P)	mg/kg	714	463	754	382	646	392	697	458	866	468	818	352	770	400	838	527
Total Weight of solids	g	554.5		1036.5		683.5		2310.5		530.0		1020.5		699.5		8048.0	

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	1800	4100	1800	4500	1800	4900	1700	4800	1800	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	680	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	28	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 B2 (Continued): Road Deposited Sediment – Metals Chemistry

Units	18-Jul-06								10-Aug-06							
	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																
Barium ug/g																
Beryllium ug/g																
Cadmium ug/g	0.698	1.29	0.69	N.D.	0.197	N.D.	0.2	N.D.	0.294	0.196	0.396	0.098	0.294	0.196	0.396	0.098
Calcium ug/g	116000	108000	107000	107000	137000	114000	136000	146000	142000	138000	143000	151000	142000	138000	143000	151000
Chromium ug/g	216	125	224	243	94.1	69.6	96.3	65.6	143	72.4	116	75.8	143	72.4	116	75.8
Cobalt ug/g																
Copper ug/g	215	95.4	220	1030	78.5	72.6	82.4	142	111	63.5	97.7	46.3	111	63.5	97.7	46.3
Iron ug/g	42100	41500	35100	50900	24900	21500	24900	234	28500	22900	26900	24900	28500	22900	26900	24900
Lead ug/g	99.8	51.9	713	210	43	29.7	44.9	28	43.2	27	48.9	25.8	43.2	27	48.9	25.8
Magnesium ug/g																
Manganese ug/g	1230	836	1010	870	605	442	652	495	354	428	617	492	354	428	617	492
Molybdenum ug/g																
Nickel ug/g																
Potassium ug/g																
Silver ug/g																
Sodium ug/g	2520	1130	4020	1920	620	404	624	412	1150	500	1040	505	1150	500	1040	505
Strontium ug/g																
Sulphur ug/g																
Tin ug/g																
Vanadium ug/g																
Zinc ug/g	557	223	546	272	200	120	213	156	278	134	254	141	278	134	254	141

Units	28-Aug-06								28-Sep-06							
	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																
Barium ug/g																
Beryllium ug/g																
Cadmium ug/g	0.396	N.D.	0.689	0.099	0.099	0.099	0.397	0.499	0.432	0.216	0.431	0.11	0.107	N.D.	0.43	N.D.
Calcium ug/g	103000	93600	101000	110000	139000	131000	151000	171000	128000	114000	129000	118000	153000	130000	145000	148000
Chromium ug/g	199	170	199	125	168	91.6	166	89.9	153	97.7	139	109	116	52	94	47.9
Cobalt ug/g																
Copper ug/g	226	132	238	125	139	458	124	77.6	187	676	227	102	98.9	87.3	111	50.5
Iron ug/g	43500	51800	39500	54300	37800	32200	29700	42100	33300	27900	25400	41000	22700	19000	19900	17300
Lead ug/g	77.2	192	134	37.6	50.8	60.9	54.4	26.9	69.9	51.9	83.2	37.7	41	110	45.4	22.5
Magnesium ug/g																
Manganese ug/g	873	790	840	726	673	495	676	603	1000	610	874	741	608	445	611	416
Molybdenum ug/g																
Nickel ug/g																
Potassium ug/g																
Silver ug/g																
Sodium ug/g	2770	1280	2680	1190	1920	832	2160	874	632	487	628	605	539	366	475	293
Strontium ug/g																
Sulphur ug/g																
Tin ug/g																
Vanadium ug/g																
Zinc ug/g	598	535	817	259	362	221	399	152	505	576	536	229	231	171	253	114

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

Units		18-Oct-06								22-Nov-06							
		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																
Barium	ug/g																
Beryllium	ug/g																
Cadmium	ug/g	0.217	N.D.	0.536	N.D.	0.107	N.D.	N.D.	N.D.	0.492	0.2	0.497	0.1	0.2	0.099	0.099	0.098
Calcium	ug/g	113000	119000	127000	112000	159000	204000	162000	182000	152000	129000	147000	150000	153000	134000	148000	171000
Chromium	ug/g	204	106	169	64.6	92.4	30.3	0.352	34.9	105	61.1	98.1	46.3	71.2	32.6	56.2	49.3
Cobalt	ug/g																
Copper	ug/g	224	74	232	72	74.2	25.7	0.426	42.2	123	76.6	163	59.8	77.4	92.7	80.3	29.2
Iron	ug/g	48400	51200	38200	30800	22500	16700	22400	17300	23700	22500	21700	22300	20000	15200	18800	16200
Lead	ug/g	68	27	76.3	31.4	30.6	21.4	35.4	15.4	53.4	235	57.3	21.8	33.5	19.7	39.6	27.3
Magnesium	ug/g																
Manganese	ug/g	1040	822	1020	670	552	401	551	414	971	585	867	536	610	379	606	477
Molybdenum	ug/g																
Nickel	ug/g																
Potassium	ug/g																
Silver	ug/g																
Sodium	ug/g	999	750	884	642	897	594	854	538	3900	1350	7290	1160	3920	1220	1490	769
Strontium	ug/g																
Sulphur	ug/g																
Tin	ug/g																
Vanadium	ug/g																
Zinc	ug/g	457	196	432	227	180	70.1	131	110	326	222	314	167	182	86.8	150	67

Table B3: Road Deposited Sediment – PAH 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
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		SBUS		NBSW		NBUS	
	< 64	64-2000	< 64	64-2000	< 64	64-2000	< 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		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
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		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
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	0.6	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

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

Units	18-Jul-06								10-Aug-06							
	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
Naphthalene	µg/g	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1-Methylnaphthalene	µg/g															
2-Methylnaphthalene	µg/g															
Acenaphthylene	µg/g	0.0130t	N.D.	0.0120t	N.D.	N.D.	N.D.	0.00600t	N.D.	N.D.	N.D.	0.0120t	N.D.	N.D.	N.D.	N.D.
Acenaphthene	µg/g	0.0250t	0.0250t	0.0120t	0.0120t	0.00600t	0.00600t	0.0120t	0.0120t	0.0120t	0.0190t	0.0120t	0.0400t	0.0120t	0.0120t	0.00600t
Fluorene	µg/g	0.0250t	0.0250t	0.0240t	0.0190t	0.0130t	0.0120t	0.0120t	0.0190t	0.0120t	0.0250t	0.0250t	0.0400t	0.0120t	0.0190t	0.00600t
Phenanthrene	µg/g	0.5	0.5	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.6	0.3	0.3	0.2
Anthracene	µg/g	0.0250t	0.0370t	0.0240t	0.0250t	0.0190t	0.0190t	0.0190t	0.0250t	0.0250t	0.0250t	0.0800t	0.0250t	0.0250t	0.0120t	0.0120t
Fluoranthene	µg/g	1.3	0.8	1.0	0.6	0.6	0.5	0.9	0.6	0.9	0.4	0.9	0.9	0.7	0.8	0.3
Pyrene	µg/g	1.1	0.6	0.9	0.5	0.6	0.4	0.7	0.5	0.9	0.0250t	0.8	0.7	0.6	0.5	0.2
Benz(a)anthracene	µg/g	0.4	0.3	0.3	0.2	0.2	0.150t	0.2	0.2	0.2	0.7	0.3	0.3	0.2	0.2	0.0870t
Chrysene	µg/g	12.9	0.6	0.9	0.4	0.6	0.3	0.8	0.5	0.8	0.5	0.8	0.6	0.6	0.4	0.2
Benzo(b)fluoranthene	µg/g	0.9	0.5	0.6	0.3	0.5	0.3	0.7	0.4	0.7	0.2	0.6	0.5	0.5	0.3	0.2
Benzo(k)fluoranthene	µg/g	0.3	0.192t	0.206t	0.0990t	0.144t	0.0930t	0.2	0.143t	0.212t	0.5	0.187t	0.190t	0.174t	0.112t	0.195t
Benzo(a)pyrene	µg/g	0.5	0.3	0.3	0.2	0.2	0.162t	0.4	0.3	0.3	0.5	0.3	0.3	0.3	0.2	0.118t
Indeno(1,2,3-cd)pyrene	µg/g	0.6	0.3	0.3	0.167t	0.3	0.143t	0.3	0.187t	0.3	0.150t	0.3	0.240t	0.3	0.187t	0.118t
Benzo(ghi)perylene	µg/g	0.151t	0.0680t	0.0850t	0.0490t	0.0690t	0.0440t	0.0930t	0.0560t	0.100t	0.3	0.100t	0.800t	0.0870t	0.0560t	0.0310t
Dibenz(ah)anthracene	µg/g	0.7	0.266	0.5	0.198t	0.3	0.181t	0.4	0.218t	0.548	0.232t	0.6	0.3	0.4	0.218t	0.124t

Units	22-Aug-06								28-Sep-06							
	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
Naphthalene	µg/g	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1-Methylnaphthalene	µg/g															
2-Methylnaphthalene	µg/g															
Acenaphthylene	µg/g	0.01t	N.D.	0.01t	N.D.	0.01t	N.D.	0.01t	N.D.	N.D.	0.00600t	0.0120t	N.D.	N.D.	N.D.	N.D.
Acenaphthene	µg/g	0.03t	0.04t	0.01t	0.006t	0.01t	0.02t	0.01t	0.00600t	N.D.	0.0250t	0.0500t	0.0310t	0.0250t	0.0250t	0.0130t
Fluorene	µg/g	0.0370t	0.03t	0.04t	0.01t	0.03t	0.04t	0.0250t	0.0130t	0.0500t	0.0370t	0.0750t	0.0440t	0.0380t	0.0370t	0.0250t
Phenanthrene	µg/g	1.1	0.4	0.7	0.1	0.6	0.6	0.6	0.3	0.8	0.5	1.0	0.7	0.6	0.4	0.4
Anthracene	µg/g	0.05t	0.03t	0.0370t	0.006t	0.04t	0.08t	0.0370t	0.0190t	0.0750t	0.0490t	0.100t	0.0560t	0.0500t	0.0560t	0.0250t
Fluoranthene	µg/g	2.7	0.7	1.3	0.3	1.2	1.3	1.3	0.5	1.2	0.8	1.6	0.8	1.1	0.6	0.7
Pyrene	µg/g	2.1	0.7	1.4	0.3	0.03t	1.0	1.1	0.4	1.2	0.6	1.1	0.5	0.8	0.5	0.6
Benz(a)anthracene	µg/g	0.6	0.3	0.4	0.9t	0.4	0.4	0.3	0.119t	0.4	0.2	0.6	0.5	0.4	0.3	0.2
Chrysene	µg/g	2.3	0.6	1.2	0.2	1.1	0.8	0.9	0.3	0.9	0.5	1.3	0.5	0.8	0.4	0.5
Benzo(b)fluoranthene	µg/g	2.1	0.6	1.1	0.1t	1.0	0.6	0.8	0.3	0.7	0.4	1.7	0.8	1.1	0.3	0.4
Benzo(k)fluoranthene	µg/g	0.7	0.2t	0.3	0.05t	0.3	0.3	0.3	0.09490t	0.3	0.148t	0.4	0.162t	0.3	0.106t	0.131t
Benzo(a)pyrene	µg/g	1.0	0.4	0.4	0.08t	0.6	0.5	0.4	0.182t	0.5	0.3	1.0	0.5	0.7	0.3	0.3
Indeno(1,2,3-cd)pyrene	µg/g	1.1	0.4	0.6	0.08t	0.6	0.4	0.5	0.163t	0.5	0.241t	1.0	0.4	0.7	0.212t	0.3
Benzo(ghi)perylene	µg/g	0.3	0.1t	0.184t	0.03t	0.2t	0.01t	0.148t	0.0560t	0.149t	0.0740t	0.225t	0.106t	0.176t	0.0750t	0.0870t
Dibenz(ah)anthracene	µg/g	1.5	0.4	1.0	0.1t	0.8	0.4	0.6	0.201t	0.584	0.3	1.0	0.3	0.6	0.212t	0.238t

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

Units	18-Oct-06								22-Nov-06							
	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
Naphthalene	µg/g	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1-Methylnaphthalene	µg/g															
2-Methylnaphthalene	µg/g															
Acenaphthylene	µg/g	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01t	N.D.
Acenaphthene	µg/g	0.3	0.03t	N.D.	0.01t	0.01t	0.02t	0.03t	0.006t	0.04t	0.02t	0.04t	0.03t	0.03t	0.02t	0.03t
Fluorene	µg/g	0.4	0.07t	0.006t	0.02t	0.02t	0.03t	0.04t	0.01t	0.07t	0.04t	0.08t	0.04t	0.04t	0.03t	0.04t
Phenanthrene	µg/g	5.2	1.1	0.1t	0.2	0.5	0.4	0.7	0.2	0.8	0.4	0.8	0.5	0.7	0.4	0.6
Anthracene	µg/g	0.7	0.07t	0.006t	0.02t	0.02t	0.03t	0.05t	0.02t	0.06t	0.04t	0.06t	0.06t	0.05t	0.03t	0.05t
Fluoranthene	µg/g	6.9	2.4	0.2	0.4	0.8	0.8	1.3	0.3	1.2	0.5	1.2	0.7	1.2	0.6	1.1
Pyrene	µg/g	4.8	2.0	0.2	0.4	0.7	0.6	1.1	0.3	1.1	0.5	1.1	0.6	1.0	0.5	0.9
Benz(a)anthracene	µg/g	2.4	0.8	0.07t	0.2t	0.3	0.3	0.4	0.1t	0.4	0.2	0.4	0.2	0.4	0.2	0.4
Chrysene	µg/g	3.2	1.9	0.3	0.3	0.6	0.5	1.0	0.2	0.9	0.4	1.0	0.5	1.0	0.4	0.9
Benzo(b)fluoranthene	µg/g	2.9	1.8	0.1t	0.3	0.6	0.5	0.8	0.2	0.7	0.3	0.9	0.3	0.9	0.3	0.8
Benzo(k)fluoranthene	µg/g	1.2	0.6	0.05t	0.09t	0.2t	0.2t	0.3	0.06t	0.2	0.1t	0.3	0.1t	0.3	0.1t	0.3
Benzo(a)pyrene	µg/g	2.7	1.0	0.09t	0.2t	0.3	0.3	0.6	0.1t	0.4	0.2	0.6	0.3	0.5	0.3	0.5
Indeno(1,2,3-cd)pyrene	µg/g	3.0	1.1	0.09t	0.2t	0.5	0.4	0.7	0.1t	0.5	0.2t	0.6	0.3t	0.6	0.2t	0.6
Benzo(ghi)perylene	µg/g	0.6	0.2t	0.03t	0.04t	0.1t	0.08t	0.2t	0.04t	0.1t	0.05t	0.1t	0.06t	0.1t	0.06t	0.1t
Dibenz(ah)anthracene	µg/g	2.0	1.0	0.1t	0.2t	0.4	0.3	0.6	0.1t	0.5	0.2t	0.6	0.2t	0.5	0.2t	0.5

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 ¹	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 C1 (continued): Simulated Runoff - Nutrient chemistry

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Volume of Water	L	200	140	100	120	110	150	120	120	120	120	120	110
pH						7	7	8	8	7	7	8	8
Conductivity	uS/cm2					610	730	350	360	360	360	4200	3800
DO	mg/L												
TOC (uv/persulf)	mg/L	discard	26	42	45	42	49	8	7	8	8	26	22
TKN (as N)	mg/L	5	5	7	5	6	6	8	8	5	6	7	7
Total Phosphorus (as P)	mg/L	2	2	2	1	1	1	2	3	2	2	3	3
Chloride	mg/L	51	120	93	93	91	120	34	40	33	36		

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		SBSW	SBUS ¹	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	NBSW	NBUS
Volume of Water	L					140	120	130	130	150	130	120	110
pH	-					8	8	8	8	8	8	8	8
Conductivity	uS/cm2					550	560	400	400	360	360	2900	2300
DO	mg/L												
TOC (uv/persulf)	mg/L	31	31	48	42	62	56	6	8	9	9	25	19
TKN (as N)	mg/L	6	7	12	10	9	8	13	12	7	8	6	6
Total Phosphorus (as P)	mg/L	4	6	3	4	2	2	8	7	4	5	2	3
Chloride	mg/L	46	57	48	53	54	65	44	47	34	32		

Table C2: Simulated Runoff – Total metals chemistry

		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	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 ¹	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	µg/L	3400	3500	14000	12000	11000	6300	16000	12000
Antimony	µg/L	6.6	7.7	29	26	25	25	44	28
Arsenic	µg/L	2.2	2.3	8.3	6.7	ND	4	8	5
Barium	µg/L	150	180	560	480	580	420	740	510
Beryllium	µg/L	ND	ND	1	0.8	ND	ND	1.1	0.9
Bismuth	µg/L	ND	ND	1.3	ND	ND	ND	2	1
Boron	µg/L	68	81	73	65	ND	60	81	64
Cadmium	µg/L	0.7	0.9	3.6	2.4	3	1.8	3.0	2.2
Calcium	µg/L	120000	110000	330000	240000	300000	190000	450000	340000
Chromium	µg/L	38	33	160	110	120	75	140	97
Cobalt	µg/L	4.1	3.4	17	13	17	8	20	12
Copper	µg/L	110	110	400	330	360	250	460	350
Iron	µg/L	14000	86000	63000	37000	65000	22000	60000	32000
Lead	µg/L	47	48	230	190	160	110	220	160
Lithium	µg/L	8.7	14	28	22	ND	10	25	17
Magnesium	µg/L	21000	19000	51000	41000	46000	30000	65000	53000
Manganese	µg/L	540	450	2600	2000	2100	1200	2400	1800
Molybdenum	µg/L	7.5	7.3	16	15	15	13	23	16
Nickel	µg/L	14	27	56	45	43	27	56	36
Phosphorus	µg/L	0.81	0.49	2.86	1.01	1.19	0.55	1.50	1.04
Potassium	µg/L	3800	4400	7100	7000	5000	4900	6400	5500
Selenium	µg/L	ND	ND	2.3	ND	ND	ND	ND	ND
Silicon	µg/L	6300	6100	24000	22000	20000	11000	28000	20000
Silver	µg/L	ND	ND	0.6	ND	ND	ND	ND	ND
Sodium	µg/L	43000	47000	29000	37000	32000	47000	28000	33000
Strontium	µg/L	410	340	690	600	720	550	770	650
Tellurium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Thallium	µg/L	0.08	0.06	0.21	0.21	ND	0.11	0.29	0.21
Thorium	µg/L	2.6	1.8	8	5.8	ND	3	8	5
Tin	µg/L	4	3.7	17	14	14	13	19	12
Titanium	µg/L	230	270	890	780	800	470	1100	730
Tungsten	µg/L	7.7	2	30	7.1	45	4	28	3
Uranium	µg/L	0.6	0.5	1.4	1.1	1	0.8	1.6	1.2
Vanadium	µg/L	15	14	60	48	34	29	63	43
Zinc	µg/L	570	600	2200	1800	1800	1300	2200	1600
Zirconium	µg/L	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	µg/L	5800	6800	9900	13000	5300	10000	47000	35000
Antimony	µg/L	9	9.6	16	20	12	23	45	53
Arsenic	µg/L	3.1	3.4	4.8	5.7	3	5	19	16
Barium	µg/L	210	230	340	450	340	520	1500	1400
Beryllium	µg/L	ND	ND	0.8	0.6	0.5	0.5	3	2
Bismuth	µg/L	ND	ND	ND	ND	ND	1	2	2
Boron	µg/L	78	68	56	68	73	74	110	100
Cadmium	µg/L	1.1	1	2	2.2	1.7	1.7	6.0	3.6
Calcium	µg/L	150000	170000	190000	230000	210000	220000	1200000	1000000
Chromium	µg/L	44	45	75	82	51	93	310	250
Cobalt	µg/L	5.6	5.6	9.7	11	8.6	10	47	35
Copper	µg/L	110	120	200	250	210	240	750	690
Iron	µg/L	20000	16000	35000	33000	25000	29000	150000	94000
Lead	µg/L	58	59	98	120	91	120	440	350
Lithium	µg/L	19	18	20	22	9	18	59	54
Magnesium	µg/L	21000	23000	37000	31000	28000	33000	120000	120000
Manganese	µg/L	610	680	1100	1400	1000	1200	5300	4400
Molybdenum	µg/L	9.9	8.5	11	15	17	24	38	36
Nickel	µg/L	17	19	30	35	21	34	120	99
Phosphorus	µg/L	0.95	0.81	1.56	1.93	0.67	1.4	3.67	3.52
Potassium	µg/L	4000	4500	4800	6200	3800	5500	11000	10000
Selenium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Silicon	µg/L	10000	11000	17000	21000	8400	19000	65000	54000
Silver	µg/L	0.5	ND	ND	ND	ND	0.8	2	ND
Sodium	µg/L	25000	26000	19000	28000	21000	25000	24000	26000
Strontium	µg/L	410	440	480	570	580	540	1900	1700
Tellurium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND
Thallium	µg/L	0.1	0.12	0.14	0.18	0.07	0.17	0.7	0.6
Thorium	µg/L	2.8	3	4.4	4.7	2	5	23	16
Tin	µg/L	4.9	4.5	7.7	8.6	6	15	28	28
Titanium	µg/L	370	410	590	690	270	720	2800	2200
Tungsten	µg/L	14	3.3	17	6.5	12	5	51	8
Uranium	µg/L	0.6	0.6	0.7	1	0.8	0.9	3.6	3.0
Vanadium	µg/L	19	20	32	37	22	39	150	130
Zinc	µg/L	560	560	1100	1300	1100	1200	3500	3000
Zirconium	µg/L	6.6	6.6	8.6	11	7	13	53	45

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

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Cadmium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	14.7	11.4
Calcium	µg/L	240000	270000	280000	15000	160000	160000	320000	200000	420000	310000	1300000	850000
Chromium	µg/L	230	220	180	77	89	76	160	90	220	150	420	300
Copper	µg/L	380	380	380	200	240	260	358	238	520	377	908	644
Iron	µg/L	63300	57200	83100	22200	31800	24000	55500	28100	74900	49300	150000	97600
Lead	µg/L	265	662	160	141	89	138	191	137	226	196	384	321
Manganese	µg/L	2600	2180	1990	908	978	897	1960	1140	2740	1880	7460	5090
Nickel	µg/L	73	70	76	29	40	32	65	33	75	54	162	118
Sodium	µg/L	21400	60800	55600	56300	58000	76600	25300	27700	25400	24900	778000	648000
Zinc	µg/L	1840	1940	1620	11100	1160	1270	1480	946	1780	1480	3760	2710

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Cadmium	µg/L	670000	1000000	66000	70000	410000	400000	1600000	1500000	1100000	1100000	1700000	1600000
Chromium	µg/L	230	340	180	160	120	110	310	290	290	300	350	350
Copper	µg/L	310	450	290	280	260	260	360	340	470	560	720	690
Iron	µg/L	98000	150000	90000	86000	61000	47000	190000	170000	140000	130000	170000	170000
Lead	µg/L	200	260	150	150	100	98	270	270	270	290	320	270
Manganese	µg/L	2700	4200	2300	2500	1500	1700	4200	3800	4100	3900	6000	5900
Nickel	µg/L	100	170	90	89	59	50	170	160	130	1310	130	190
Sodium	µg/L	25000	31000	30000	33000	36000	41000	36000	37000	27000	27000	470000	350000
Zinc	µg/L	1500	2400	1400	1300	1200	1200	1500	1500	1590	1800	1600	2400

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 ¹	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

		9-Aug-05		30-Aug-05		4-Oct-05		27-Oct-05	
	Units	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 C3 (Continued): Simulated Runoff – Dissolved metals chemistry

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Cadmium	µg/L											N.D.	0.0850t
Calcium	µg/L	44100	55000	56000	57900	59200	58700	41700	42200	44400	44800	84200	93200
Chromium	µg/L	1.42	4.01	2.4	4.67	2.07	3.23	ND	ND	1.08	1.31	3.68	3.96
Copper	µg/L	11.7	29.3	29	43.9	34.6	48.9	9.95	11	13.5	14	27.2	27.7
Iron	µg/L	23.7	37.8	133	44.1	60.4	35.2	108	42.4	73.5	42.3	106	57.7
Lead	µg/L	14	14.9	7.85	5.09	1.04	0.71	7.17	6.15	6.27	5.61	N.D.	N.D.
Manganese	µg/L	53.6	69.2	134	98.9	118	86.1	28.1	18	99.5	25.8	146	141
Nickel	µg/L	0.839	1.19	4.32	4.14	5.4	4.13	2.2	0.7	ND	0.159	4.27	4.96
Sodium	µg/L	21300	60200	54400	56000	57100	76000	20700	24200	20100	22900	614000	612000
Zinc	µg/L	19.3	82	33.2	140	123	142	31.4	44.9	32.8	60.3	27.6	36.8

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Calcium	µg/L	58100	57600	58800	57400	65500	65500	47600	49200	45900	46300	88300	73300
Chromium	µg/L	2.25	3.28	2.56	3.23	1.9	2.61	ND	ND	1.48	1.55	3.55	3.52
Copper	µg/L	22	19.7	20.5	21.8	34.8	37.5	7.55	3.8	9.11	11.5	26.8	26.7
Iron	µg/L	5.72	77.5	28.8	78.7	56.1	55.8	54.6	50.7	69.3	66.1	34.9	39.2
Lead	µg/L	11.1	8.62	6.98	1.27	1.07	0.91	15.5	14.5	11.5	4.65	N.D.	N.D.
Manganese	µg/L	83.4	70.3	115	54.6	142	71.9	23.9	25.6	26.2	20	103	77.2
Nickel	µg/L	2.54	3.45	3.03	3.24	4.97	3.53	ND	0.61	ND	ND	4.73	4.66
Sodium	µg/L	21200	28600	28600	31600	32700	39100	23900	26100	18600	20000	455000	315000
Zinc	µg/L	13.1	18.1	17.6	19.6	45.1	50.2	12.8	13	7.73	10.6	16.7	20.1

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
Benz(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 ¹	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
Benz(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

Table C4 (Continued): Simulated Runoff - PAH chemistry

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS	NBSW	NBUS
Naphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N.D.	N.D.
Acenaphthylene	µg/L	ND	ND	ND	ND	0.0	0.0	0.0	0.0	0.1	0.1	N.D.	N.D.
Acenaphthene	µg/L	ND	ND	0.1	0.1	ND	ND	0.1	0.1	0.1	0.2	N.D.	N.D.
Fluorene	µg/L	ND	ND	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1t	0.1t
Phenanthrene	µg/L	0.9	1.1	1.5	0.9	0.9	0.7	1.5	1.4	2.6	3.0	0.6	0.4t
Anthracene	µg/L	ND	0.1	0.1	0.1	ND	ND	ND	0.1	0.3	0.4	N.D.	N.D.
Fluoranthene	µg/L	3.0	2.7	3.4	1.6	2.5	1.6	3.4	3.0	5.2	5.9	0.8	0.6t
Pyrene	µg/L	2.6	2.2	2.9	1.5	2.1	1.5	2.9	2.6	4.3	5.1	0.8	0.6t
Benz(a)anthracene	µg/L	1.4	1.2	1.3	0.5	0.8	0.5	1.3	0.9	1.4	1.2	0.2t	0.2t
Chrysene	µg/L	2.4	1.9	1.9	0.9	1.9	1.5	2.3	1.8	3.2	4.0	0.4t	0.3t
Benzo(b)fluoranthene	µg/L	3.4	2.4	2.5	1.7	2.9	2.2	2.9	1.8	3.4	6.8	1.3	0.9
Benzo(k)fluoranthene	µg/L	1.3	1.3	0.7	0.3	0.5	0.3	0.9	0.7	1.1	1.4	0.2t	0.3t
Benzo(a)pyrene	µg/L	2.1	2.0	1.7	0.6	1.4	0.7	1.6	1.2	2.4	1.6	N.D.	N.D.
Indeno(1,2,3-cd)pyrene	µg/L	2.6	2.8	1.7	0.5	1.8	1.4	1.3	1.4	2.2	2.1	2.3	2.9
Dibenzo(ah)anthracene	µg/L	0.6	0.7	0.9	0.1	0.3	0.3	0.5	0.3	1.2	0.9	2.6	2.6
Benzo(ghi)perylene	µg/L	1.7	2.0	1.8	0.9	1.7	1.5	1.7	1.2	2.5	3.7	2.8	2.1

	Units	18-Jul-06		10-Aug-06		22-Aug-06		28-Sep-06		18-Oct-06		22-Nov-06	
		SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS	SBSW	SBUS
Naphthalene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N.D.	N.D.
Acenaphthylene	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.1	0.0	N.D.	N.D.
Acenaphthene	µg/L	ND	ND	0.1	0.1	0.0	0.1	0.0	ND	0.2	0.1	N.D.	N.D.
Fluorene	µg/L	ND	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.3	0.1	0.1t	0.1t
Phenanthrene	µg/L	1.6	3.6	2.0	1.6	0.9	1.1	0.4	0.4	4.7	2.0	1.5	0.7
Anthracene	µg/L	0.1	ND	0.1	0.1	ND	ND	0.0	ND	0.3	0.2	0.1t	N.D.
Fluoranthene	µg/L	3.6	7.7	4.0	3.2	2.2	2.7	0.8	0.7	8.5	4.2	2.7	1.3
Pyrene	µg/L	2.7	5.6	3.1	2.4	1.8	2.2	0.7	0.5	6.7	3.4	2.3	1.1
Benz(a)anthracene	µg/L	1.5	2.7	1.5	1.3	0.7	1.3	0.3	0.2	2.4	1.6	1.0	0.5t
Chrysene	µg/L	2.5	4.6	2.3	1.9	1.7	2.2	0.6	0.5	4.4	2.4	1.3	0.7
Benzo(b)fluoranthene	µg/L	4.1	6.2	3.0	2.6	2.6	3.2	0.6	0.6	4.5	3.1	3.2	2.0
Benzo(k)fluoranthene	µg/L	1.1	1.7	0.8	0.7	0.4	0.5	0.2	0.2	1.1	0.9	0.8t	0.3t
Benzo(a)pyrene	µg/L	2.5	5.2	2.0	1.8	0.9	1.6	0.4	0.3	2.4	2.0	2.3	N.D.
Indeno(1,2,3-cd)pyrene	µg/L	3.9	7.7	1.8	1.7	1.8	1.9	0.6	0.5	3.1	1.7	1.4	2.0
Dibenzo(ah)anthracene	µg/L	0.9	1.5	0.3	0.3	0.3	0.3	0.3	0.3	1.4	1.0	0.8t	1.9
Benzo(ghi)perylene	µg/L	2.5	4.4	1.8	1.7	1.5	1.7	0.6	0.5	3.0	1.8	1.7	2.5

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