TORONTO STAFF REPORT

June 13, 2005

To: Works Committee

From: W. Leslie Kelman, Acting General Manager, Transportation Services
William G. Crowther, Executive Director, Technical Services

Subject: PM_{10} and $PM_{2.5}$ Efficient Street Sweepers for the City of Toronto
(All Wards)

Purpose:

To report on and seek approval for the preferred technology for the future purchase of PM10 and PM2.5 Efficient Street Sweepers and the adoption of the Street Sweeper Testing Protocol as the City of Toronto's interim standard to be used in future requests for proposals to secure these types of sweepers.

Financial Implications and Impact Statement:

Currently, funding has been identified by Fleet Services within the Corporate Vehicle and Equipment Replacement Reserve (CVERR) for the purchase of new PM_{10} and $PM_{2.5}$ efficient street sweepers.

Recommendations:

It is recommended that:

(1) to meet the direction approved by City Council on the purchase of $PM_{10,}$ and $PM_{2.5}$ efficient street sweepers, staff be authorized to issue a request for proposals (RFP) limited to regenerative-air street sweeper technology;

(2) the PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol, as described in “Appendix B”, be adopted as the City of Toronto’s interim standard to be used in future RFP’s for PM_{10} and $PM_{2.5}$ efficient street sweepers;

(3) Fleet Services be requested to report to the Policy and Finance Committee in the Fall of 2005 confirming the allocation of funding for the purpose of purchasing new regenerative-air street sweepers within the Corporate Vehicle and Equipment Replacement Reserve;

(4) this report be forwarded to the Policy and Finance Committee for information to be considered at the same time as Fleet Services' report on the allocation of funds within the Corporate Vehicle and Equipment Replacement Reserve;

(5) this report be forwarded to the Board of Health for information; and

(6) the appropriate City Officials be authorized and directed to take the necessary action to give effect thereto.

Background:

The Toronto Interdepartmental Environmental (TIE) Team, at it's meeting of April, 2002, received a presentation from Technical Services Division staff outlining findings of an air quality study which indicated that a major source of particulate matter (PM_{10}) in Toronto's air is fine road dust. The City of Toronto, like many other municipalities, provides the essential public service of street sweeping to keep City streets clean. Currently, the City's fleet of mechanical street sweepers is limited, by their technology, in the ability to remove significant amounts of that fine road dust. However, there are currently in the marketplace, manufacturers of new street sweeping technologies that are reportedly capable of removing 80% of the particulate matter from a road surface. At the request of TIE, Transportation and Technical Services staff were asked to further investigate the potential merits of alternative street sweeping technologies capable of removing PM_{10}. Fine road dust originates mainly from asphalt, rubber tire, and brake disc and pad wear. Removing much of the fine road dust from the City's roads could lead to a substantive improvement in the City's ambient-air quality. Preliminary discussions between the two service areas revealed that several activities should be undertaken in examining new street sweeping technologies. This collaborative effort between the two groups was called the Clean Roads to Clean Air (CRCA) initiative.

In 2004, the Auditor General [Clause No. 2 in Report No. 2 of the March 11, 2004 meeting of the Audit Committee entitled 'Fleet Operations Review – Phase I'] identified sweepers as a high replacement priority for the organization because the ageing fleet of sweepers are well beyond their life-cycle. Currently the street sweeper fleet is experiencing increased downtime for unscheduled repairs, significantly affecting the ability of Transportation Services staff to meet the street sweeping service levels.

Most recently, City Council at its meeting on April 12, 13 and 14, 2005, adopted a report (Clause No. 21 of Report No. 4 of the Policy and Finance Committee) from the Roundtable on the Environment, dated March 17, 2005, entitled "Short-Term Deliverables and Other Requests from the Roundtable on the Environment for improving Toronto's Air Quality", which recommended, among other things, that the purchase of PM_{10} and $PM_{2.5}$ Efficient Street Sweepers be given a high priority for this year or next year, subject to normal budget approval, as one of the short-term deliverables for improving the City of Toronto's air quality.

Comments:

The CRCA work program included several studies, leading to the development of a PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol, as well as the actual testing of several street sweepers both in controlled and real world environments. The objective of the CRCA initiative was to evaluate the City's existing mechanical-type sweepers and new technology street sweepers (i.e. various models of new regenerative-air and vacuum-assist technology) and to provide quantitative evidence that new technology street sweepers would in fact be effective in improving air and stormwater quality. Testing was also done to establish if the new technology sweepers could meet the City's clean street objectives effectively in year-round operations (i.e. sweeping without water during days with subzero temperatures and operating appropriately during Smog Alert days).

The CRCA project supports the goals and objectives of several corporate initiatives. Those initiatives include Council's Strategic Plan, the Environmental Plan, Clean and Beautiful City, Green Fleet Transition Plan, Air Quality Improvement Strategy and Wet Weather Flow Management Master Plan. In addition, the CRCA project tries to achieve the City Council priority to make Toronto a clean, green and sustainable city by integrating environmental stewardship into daily activities, such as street sweeping, to maintain and improve the health of the environment for present and future generations.

Health Impacts

In July 2004, Toronto Public Health published a report entitled the "Air Pollution Burden of Illness in Toronto". The report indicates that air pollution in our city contributes to about 1,700 premature deaths and 6,000 admissions to hospitals each year. Current mortality estimates for Toronto are based on the health risk associated with acute (short-term) exposure to ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2), as well as chronic (long-term) exposure to fine particles. Approximately 1,200 premature deaths are estimated to be attributable to chronic exposure to $PM_{2.5}$. Approximately 180 premature deaths are estimated to be attributable to acute exposure to PM_{10} annually. Other Toronto annual estimates for the health impacts of Inhalable Particulates (PM_{10}) show that there are over 400 cardiovascular hospitalizations, almost 600 respiratory hospitalizations, approximately 1,200 cases of adult chronic bronchitis, almost 6,000 emergency room visits, 12,000 cases of bronchitis in children and almost 72,000 asthma symptoms days each year. In addition to the more serious health effects associated with air pollution, less serious health outcomes (such as chronic bronchitis, emergency room visits and number of days that people experience asthma symptoms) affect tens of thousands of people in Toronto each year.

These types of studies provide an important context for the development of policies and programs that promote and protect the public's health. Given the size of the health risk associated with Toronto's air pollution, the Burden of Illness study reinforces the importance of taking actions at all levels of government to ensure that the public and private sectors intensify air improvement initiatives. Exposure to each additional $10 \mu g/m^3$ of PM_{10} is anticipated to increase non-traumatic mortality in the exposed population by another 0.6% [Air Pollution Burden of Illness in Toronto: 2004 Summary (July 2004)].

Toronto Street Dust Monitoring Study

Inhalable particulates are particulate matter of aerodynamic diameter smaller than 10 microns (PM_{10}). Respirable particulates are a subset of PM_{10} and are particulate matter of aerodynamic diameter smaller than 2.5 microns ($PM_{2.5}$). In May 2000, the Canadian Environmental

Protection Act (CEPA) identified PM_{10} as a “toxic” substance, and $PM_{2.5}$ is a major, and common, determinant of poor air quality and smog days.
While standard network monitoring station data (as provided by MOE) helps to represent a regional overview, it is not necessarily representative of local situations for all parameters, and especially not for the coarse fraction of PM_{10} on city streets. Additional on-street monitoring was undertaken in select areas of the City to address this. A more detailed summary of the dust monitoring study is documented in Appendix ‘A’.

The monitoring study revealed that PM_{10} (including $PM_{2.5}$) is a major local issue on the downtown streets that were examined. Nose-level concentrations of PM_{10} and $PM_{2.5}$ during the daylight hours were consistently higher than the 24-hour Ambient Air Quality Criteria (AAQC) for PM_{10} ($50 \mu g/m^3$) and higher than the 24-hour Canadian Wide Standard (CWS) for $PM_{2.5}$ ($30 \mu g/m^3$). Monitoring was undertaken to assess exposure concentrations for motorists, cyclists and pedestrians on downtown streets during the daytime. All three groups are consistently exposed to higher concentrations of PM_{10} and $PM_{2.5}$ than the AAQC and CWS values. Further study revealed less widespread and less significant exceedances in other Districts of the City and lower values during hours of darkness and weekends.

The high street level air concentrations of PM_{10} and $PM_{2.5}$ relate to input factors (traffic volumes and speeds, and vehicle size), exacerbating factors (such as street design adversely impacting street ventilation), mitigating measures (such as on-street trees and other vegetation that trap particles), and output factors (natural rainfall and city “flushing” with water; sweeper technology and frequency to remove road dust from streets and to prevent its re-entrainment by passing vehicles).

Further street dust monitoring on City streets is required to better resolve remaining uncertainties, including a greater clarification of night-time and weekend PM_{10} and $PM_{2.5}$ levels.

Stormwater Quality Study

In July 2004, Toronto Water, Transportation Services and the National Water Research Institute of Environment Canada initiated a two-year study to evaluate the effectiveness of street sweeping in stormwater pollution source control. The objective of the study is to assess and compare the effectiveness of several different types of street sweepers in the capture of PM_{10} from street sediments so as to reduce health risks associated with this material being dissolved and transported by urban runoff into catchbasins. The study will evaluate the stormwater quality by measuring the toxicity with limited chemical characterization. Findings of this study will be made available in a future report.

PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test

In 2004, Transportation Services and Technical Services staff developed the “PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol”. It was designed for the purpose of evaluating a street sweeper’s year-round PM_{10} and $PM_{2.5}$ efficiency without the use of water and/or side broom shrouds for dust control and suppression. More details on the protocol are available in Appendix ‘B’.

In July and August of 2004, the PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol was used at the Disco Yard facility. An enclosed tunnel constructed with continuous sealed tarpaulin was built inside the Disco Yard facility in order to minimize extraneous disturbance (i.e. from wind or precipitation) and loss of the applied test material.

A total of 15 days of controlled testing was carried out on a total of eight street sweeper models, which included several mechanical vacuum-assist and regenerative-air models. The testing included street sweepers currently on the market and some from the City's existing fleet complement. The outcome of the testing allowed City staff to determine the following performance efficiencies for each sweeper tested:

- "Removal of Material from Test Track Surface" – amount of material picked-up and removed;
- "Material disturbed and deposited elsewhere" – deposit on sidewalk; and
- "Material disturbed into the air" – PM_{10} & $PM_{2.5}$ air concentrations.

The results of the findings are summarized in Table No. 4 of Appendix 'C'. For the purpose of protecting the identity of all manufactured models involved in the testing, the sweepers have been labelled as Sweeper 1, 2, 3, etc.

The overall test findings clearly show that new technology street sweepers can achieve high performance levels for PM_{10} and $PM_{2.5}$ removal, and that regenerative-air models achieve the highest efficiency performance for both PM_{10} and $PM_{2.5}$ in all three key criteria categories.

The results indicate that regenerative-air technology has the capability of achieving:

- greater than 90% surface removal efficiency;
- material deposit on sidewalks as low as 0.07%;
- the lowest PM_{10} air contamination concentration (10.35 mg/m^3/kg – total concentration); and
- the lowest $PM_{2.5}$ air contamination concentration (3.95 mg/m^3/kg – total concentration).

These performance efficiencies would be desirable for minimum threshold levels when considering the purchase of this type of technology. However, staff will be using these numbers as a guide in determining the appropriate threshold levels for the three key criteria categories. Performance efficiencies should be included as part of any future street sweeper specifications.

The PM_{10} and $PM_{2.5}$ efficiency test results provide clear evidence that regenerative-air street sweepers are the most PM_{10} and $PM_{2.5}$ efficient in the category of new technology street sweepers, and that they clearly outperform mechanical street sweepers. The regenerative-air technology is unique in that the air is "swirled" at high speed creating a cyclonic effect to help remove particulate matter. The efficiency was observed to be much higher than many of the other technologies in picking up and removing fine particulate matter from the test track surface. In addition, the technology demonstrated the ability of minimizing the amount of PM_{10} and $PM_{2.5}$ material disturbed into the air during the street sweeping process.

Operational Performance Evaluation

Before endorsing the use of regenerative-air street sweepers for the City of Toronto, Transportation staff undertook a review of the operational effectiveness of two new technology street sweepers, both of which had been tested at the Disco Yard facility. Toronto staff, in collaboration with the City of Hamilton, carried out an objective evaluation of those two new technology sweepers that are currently within the City of Hamilton fleet. The evaluation included the following three categories: equipment maintenance; operational performance; and ergonomics. City staffs' evaluation confirmed the earlier findings by the City of Hamilton, who had circulated a questionnaire to their own operators to evaluate the effectiveness of those same sweepers. The results of the evaluation indicated that the regenerative-air street sweeper effectively met key operational requirements, such as:

- efficient leaf and heavy silt loading pick-up;
- efficient pick-up of large debris;
- ability to operate during wet conditions (rain);
- ability to operate below zero temperatures; and
- ability to operate in a dry, dustless mode.

With the permission of the City of Hamilton, the City of Toronto has been allowed to use and publish the data compiled by Hamilton staff in their survey. The results of their findings, subsequently confirmed by City of Toronto staff, are presented in Table No. 5 of Appendix 'D'.

Based on the results of the Efficiency Test and the Operational Performance Evaluation, regenerative-air technology is recommended to be used to meet PM_{10} and $PM_{2.5}$ efficiency targets for street sweeping, and any future RFP issued for PM_{10} and $PM_{2.5}$ efficient street sweepers should be limited to this technology. It is further recommended that the PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol, described in Appendix 'B', be used as an interim standard in future RFP's for PM_{10} and $PM_{2.5}$ efficient street sweepers.

Replacement of Street Sweepers

There are currently 50 mechanical street sweepers in Transportation Services' fleet inventory. A typical street sweeper is designed to operate effectively for a period of seven years. There are also several City street sweepers, within the current City complement, that operate 24/7 due to higher levels of service on some of the more prominent roads in the downtown core, shortening the expected serviceable life of those sweepers down to three or four years. Currently there are 28 street sweepers that are overdue for replacement in 2005. Table No. 1 summarizes the age distribution of the City's current fleet of sweepers.

Table No. 1 - Fleet Inventory of Street Sweepers by Age

Category	**Less than 5 Years**	**5 to 8 Years**	**9 to 10 Years**	**11 to 15 Years**	**Total**
Mechanical Sweepers	22	5	11	12	50

Fleet Services staff have reviewed annual maintenance records (i.e. parts, labour costs) dating back four years for the mechanical street sweepers. Records revealed that an annual average maintenance cost of approximately $20,000.00 per sweeper could be saved if the old equipment were replaced. However, actual savings are yet to be determined and will depend on usage and operating conditions in Toronto.

Transportation Services staff have been in consultation with staff from Fleet Services, keeping them informed of the progress made with the Clean Roads to Clean Air (CRCA) Program and on all test findings compiled to-date. Fleet Services has worked collaboratively with Transportation Services and is supporting the direction taken to replace the sweepers which are currently beyond their life-cycle. In support of the initiative, Fleet Services has identified funding within the Corporate Vehicle and Equipment Replacement Reserve for the purchase of new regenerative-air street sweepers. To confirm this funding, it is recommended that Fleet Services be requested to report back to the Policy and Finance Committee in the Fall.

Should the Works Committee and City Council approve the purchase of new regenerative-air street sweepers, staff will review the potential changes in future street sweeping and flushing levels of service, identify any impacts on fleet requirements and any associated operating budget implications, and report back to the Works Committee at a future date.

At present, it is envisioned that the regenerative-air sweepers will be used on the arterial network, where the highest concentration of PM_{10} and $PM_{2.5}$ currently exists, while the mechanical street sweepers, which would still be essential for specific sweeping conditions, will continue to be used primarily on collector/local roads. Taking into consideration the total kilometres of the arterial road network and the street sweeping level of service delivered on those arterial roads, the target ratio of regenerative-air versus mechanical street sweepers would be 60% regenerative-air and 40% of mechanical-type.

Process to be Used for Selecting Successful Vendor

An RFP process will ensure fairness to all suppliers of regenerative-air street sweepers and ensure that the City's future investment in the equipment will significantly contribute to improving Toronto's air and stormwater quality while meeting operational needs in a cost-effective manner. The regenerative-air street sweepers will be evaluated using, but not be limited to, the following criteria categories:

1. *General Specifications*

   (a) general mechanical and functional requirements;
   (b) operational requirements (operate efficiently during leaf pick-up, ability to pick-up debris adjacent to the curb efficiently without the use of gutter brooms (using main vacuum), ability to operate efficiently under wet conditions without affecting the performance of the filtration system);

2. *Performance Specifications*

   PM_{10} and $PM_{2.5}$ criteria (thresholds for removal of material from surface (%), deposit on sidewalk (%) and PM_{10} and $PM_{2.5}$ air contamination)

3. *Performance Evaluation*

Performance evaluation may include the following: service availability, ergonomics, visibility, ease of use and handling, comfort, safety features, etc.

4. *Total Cost of Ownership*

Purchase cost plus an average maintenance cost (i.e. includes fuel consumption and parts replacement over a three-year period) will be the final determining factor in the case where more than one vendor was successful on the above elements.

Vendors will be required to provide their street sweeper, at no cost to City of Toronto, for two separate evaluations: PM_{10} and $PM_{2.5}$ efficiency testing; and Performance Evaluation. Should the vendors prefer, they will have the option of providing the City of Toronto with third-party documentation containing test data for each of the PM_{10} and $PM_{2.5}$ criteria, attained using the City of Toronto Street Sweeping Testing Protocol. In the event that the vendors cannot provide this data, they will be asked to make their equipment available for testing by the City of Toronto. Any vendor refusing to have their equipment tested will automatically be excluded from any further consideration.

Conclusions:

The objective of the Clean Roads to Clean Air initiative was to assess how effective new technology street sweepers are in removing fine particulate matter (PM_{10} & $PM_{2.5}$) from the City's paved roads year-round, thereby delivering the City street sweeping service in a manner that would significantly contribute to improving overall human health, air and stormwater quality.

After several studies and equipment tests, the findings clearly support the recommendation of regenerative-air technology as the City of Toronto preference for PM_{10} and $PM_{2.5}$ efficient street sweepers. The future use of these types of sweepers in the City of Toronto, ultimately envisioned to be 60 % of the fleet complement, would result in a 92% combined surface and air removal efficiency of PM_{10} & $PM_{2.5}$ material. Findings from the Air Quality Improvements Branch (AQIB) Dust Monitoring Study further suggest that air quality in the City would improve by 21% or see a reduction of $10.5\mu g/m^3$ in PM_{10} exposure concentration. In addition, cross-benefits of removing toxic loads from the streets, instead of being washed down the catchbasins, would have a positive impact on stormwater quality and the cost of stormwater treatment.

The replacement of mechanical street sweepers with regenerative-air types will, in the short term, help to start reducing the backlog of overdue sweepers, which currently stands at 28 for 2005. The ageing fleet is impacting the delivery of street sweeping service levels across the City and will continue to do so if replacement of overdue equipment continues being postponed.

Fleet Services has identified funds within the Corporate Vehicle and Equipment Replacement Reserve for the purchase of regenerative-air street sweepers. Confirmation of this funding will be made when Fleet Services reports to the Policy and Finance Committee in the Fall of 2005.

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List of Attachments:

Appendix ‘A’ – Toronto Street Dust Monitoring Study
Appendix ‘B’ – Toronto PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol
Appendix ‘C’ – PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test
Appendix ‘D’ – Operational Performance Evaluation

APPENDIX 'A'

Toronto Street Dust Monitoring Study

Air Quality Modelling performed in 2001/2 by AQIB indicated a citywide, year-round problem with PM_{10} (including $PM_{2.5}$). (No other parameter indicated similar concerns would be warranted). The results of the AQIB air quality modelling were not supported by MOE data. External expert assistance showed that because MOE Air Quality (AQ) Station Data is collected at what can be thought to be too great a distance from arterial roads and at too great a height, that concentrations on city streets could well be much higher than MOE data might indicate. Generally, urban particulate concentrations are difficult to predict and regional or community air monitoring data (as operated by MOE) are unlikely to fully reflect roadside inhalable particulate level severity. It was concluded that street data should be different from MOE AQ Station data but that the hypothesis needed to be more fully tested. Consequently, additional on-street monitoring was required.

Exposure to urban sources of inhalable particulate matter within Toronto is most likely of greatest concern for persons using or dwelling near major municipal traffic routes. The highest potential outdoor concentrations of re-suspended fine road dust and vehicle exhaust can be anticipated at the street level, especially within high traffic and poorly ventilated street canyon (between tall buildings) locales.

The purpose for having performed on-street monitoring of PM_{10} concentrations on City streets was to determine and potentially answer the following:

- Do Toronto streets have a real PM_{10} concentration problem?
- What is the major source of the problem?
- Who is most at risk?
- Are there measurable differences between land use, classification of road and other factors (e.g. street sweeping frequency)?

The on-street monitoring study was implemented in two phases and undertaken in selected areas across the entire City of Toronto.

Phase I - Monitoring

The main objective of the Phase I of the Toronto Street Dust Monitoring Study was to measure and provide monitoring data of ambient particulate matter (PM_{10} and $PM_{2.5}$) concentrations, while travelling along several streets and at street intersections in downtown Toronto. The data collected included maximum concentrations of PM_{10} and $PM_{2.5}$ at nose level for pedestrians, cyclists and motorists along streets. The monitoring was done on roadways and sidewalks in a series of replicated measurements to determine the nose level PM_{10} and $PM_{2.5}$ exposure levels of road users during the daytime and under high traffic situations. The measurements were collected during mid-November to early-December 2003 between 10:00 a.m. and 7:00 p.m.

Phase II – Monitoring

The study objective of Phase II was consistent with Phase I. In this phase, the objective was to obtain data for night-time and weekend concentrations to augment the day-time readings of Phase I and expand the geography to include study areas in Etobicoke Town Centre, North York Town Centre, Scarborough Town Centre and downtown Toronto. These study areas represent a wider range of land use types and densities, traffic density, and sweeper frequency conditions. The measurements were collected during the Summer and Fall of 2004. The selected routes in each study area were also fixed to MOE monitoring stations in which $PM_{2.5}$ is regularly measured (i.e. this would allow for future data comparisons to be made). The Toronto route was identical to that monitored previously in Phase I. Although localized building construction occurred in a limited number of downtown locations, there was no significant roadway construction within any of the monitoring routes. Also there were no significant non-paved road dust sources along or close to the routes selected within the local areas examined.

Phase I - Findings

Phase I of the monitoring study characterized the nose level particulate levels to which motorists, cyclists and pedestrians are exposed as well as to estimate the associated road dust contribution. Although not directly comparable, the MOE 24-hour Ambient Air Quality Criteria (AAQC) – PM_{10} (50μg/m^3) and Canada Wide Standard (CWS) 24-hour – $PM_{2.5}$ (30μg/m^3) was used as a comparative air quality objective. [Data collected at MOE's regional AQ Stations has yet to be released. Comparative analysis will be performed when possible, but close correlation is not expected due to the reasons provided previously (ie local street concentrations will have much higher concentrations than those at stations distant from major roads and too high in the sky].

Table No. 2 represents a summary of averaged mean exposure concentrations along the monitored routes during daylight hours.

Table No. 2 - Averaged Mean Exposure Concentrations (PM_{10} & $PM_{2.5}$) for Phase I

Types of Exposure	**Number of Test Sequences**	**Circuit Average Concentration (μg/m^3)**	
		PM_{10}	**$PM_{2.5}$**
Motorist	7	54	45
Cyclists	6	71	41
Pedestrians	6	66	40
Motorist (Highway)	2	84	64

The key findings resulting from the Phase I monitoring study were as follows:

- Downtown streets have fine particulate concentrations of PM_{10} and $PM_{2.5}$ during daylight hours that are consistently higher than the 24-hour AAQC for PM_{10} and higher than the 24-hour CWS for $PM_{2.5}$;
- The charted pattern of PM_{10} and $PM_{2.5}$ variations are similar with $PM_{2.5}$ effectively representing the baseline of traffic exhaust plus regional (trans-boundary) inputs;
- Exposure to urban sources of inhalable particulate matter within Toronto is most likely of greatest concern for persons using or dwelling near major municipal traffic routes;

- Highest concentration of re-suspended road dust and vehicle exhaust can be anticipated at the street level, especially within high traffic and poorly ventilated street canyon locales;
- Inhalable (PM_{10}) particle concentration range primarily depends on factors such as: traffic volume, vehicle type/speed, road dust loadings, silt size, micrometeorological and street ventilation conditions;
- Main road users and those nearby (e.g. motorists, cyclists, pedestrians, shopworkers, residents, and certain municipal employees, etc) are the most likely to be exposed to traffic-related emissions; and
- Road dust contributed more than 43% of the measured PM_{10} and practically 100% the coarse inhalable fraction ($PM_{2.5\text{-}10}$), since no other major source of dust occurred on the study routes. (Monitored results from locations immediately adjacent to downtown construction activity sites were examined and shown not to cause increased concentration levels.)

It is theoretically probable that even higher readings could be expected in other seasons of the year and in areas with less frequent street sweeping and where effective removal is not occurring. More extensive monitoring is required to determine if street level PM_{10} and $PM_{2.5}$ exposure concentrations in this and other suburban areas regularly exceed the 24-hour AAQC and CWS levels.

Phase II – Findings

Table No. 3 - Averaged Mean Exposure Concentrations (PM_{10} & $PM_{2.5}$) for Phase II

Study Area	**Types of Exposure**	**Number of Test Sequences**	**Circuit Average Concentration (µg/m^3)**	
			PM_{10}	**$PM_{2.5}$**
North York Weekdays	Cyclists	16	44	25
	Pedestrians	5	45	32
Scarborough Weekdays	Cyclists	16	62	31
Etobicoke Weekdays	Cyclists	12	65	27
	Pedestrians	8	38	24
Downtown Toronto Weekend	Cyclists	8	31	23
Downtown Toronto Week Night	Cyclists	8	(130)*	(115)*

* The data collected during the one night of testing are considered invalid due to the presence of weather related excessive fine droplet moisture which affected the equipment's ability to monitor similar sized particles. However, the coarse fraction of $PM_{2.5\text{--}10}$ (i.e. PM_{10} minus $PM_{2.5}$) is still considered to be a valid data set. The coarse fraction data obtained is in keeping with other results obtained during daylight periods.

The key findings resulting from the Phase II monitoring study were as follows:

- Comparisons between areas, in the absence of consideration of the other factors such as the differences due to traffic volumes, sweeper frequency, land use and density, is not advised.
- Users of roads in the East, West and North Districts are generally less impacted by excessive fine particulate dust than users of roads in the South District (downtown).
- All four districts had similar exposure concentrations where all related factors (e.g. land use density, traffic density and sweeper frequency) were similar.
- Overnight concentrations are uniformly lower than daytime concentrations.
- Weekend concentrations are also uniformly lower than weekday concentrations.
- The lowest concentrations occur in “quiet” low-traffic, low-density residential areas.
- The highest concentrations occur along **major arterial roads**.
- High concentrations are noticeable where traffic volumes are very high but speeds are slow and where traffic volumes are lower but speeds are high (Further study and clarification regarding the relationship between traffic volumes, traffic operating speeds and air-borne PM_{10} and $PM_{2.5}$ concentrations are required).
- The influence of urban design (buildings in close proximity to the streetline) limits air ventilation resulting in fine particles in the air being trapped. Further study and evaluation is required.
- The frequency of street sweeping (in combination with other determining factors) also influences particulate concentrations on City streets.

APPENDIX ‘B’

Toronto PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol

The California Air Resources Board (CARB), South Coast Air Quality Management District (SCQMD) of Los Angeles, California adopted the SCQMD Test Protocol, Rule 1186: Certified Street Sweeper Compliance Testing in September 1999. The purpose of Rule 1186 was to describe a test protocol for gauging the PM_{10} efficiency of street sweeping equipment and to establish procedures to present test results. PM_{10} efficiency in Rule 1186 includes both the equipment’s ability to remove typical urban street silt loading and to limit the amount of PM_{10} disturbed into the air during the sweeping process.

Since Rule 1186 was limited in the types of results that Toronto was seeking, it was decided by Transportation and Environmental Services staff that a Toronto protocol would be more appropriate. The City of Toronto, “PM_{10} and $PM_{2.5}$ Street Sweeper Testing Protocol” was designed for the purpose of evaluating a street sweeper’s year-round PM_{10} and $PM_{2.5}$ efficiency without the use of water and/or side broom shrouds for dust control and suppression. Reliance on water for dust suppression in the freezing temperatures of Toronto’s climate would limit the use of sweepers during the winter season, thereby reducing the opportunities to sweep. Another key consideration in the protocol is the non-use of shrouds as a dust suppression mechanism. City staff has observed repeatedly that when street sweepers operate with shrouds the sweeper’s operational performance is impacted under certain sweeping conditions (e.g. large debris and leaf pick-up) and that the shrouds need frequent replacement resulting in high maintenance costs.

The method used under the Toronto Street Sweeper Testing Protocol examines the street sweeper’s ability to:

- operate in Toronto’s climate;
- capture and remove PM_{10} and $PM_{2.5}$ from a typical Toronto urban street surface; and
- limit the amount of PM_{10} and $PM_{2.5}$ that is disturbed (or entrained) into the air and subsequently deposited adjacent to the paved road surface.

The protocol was intended to provide an objective and quantitative method for assessing both the relative maximum PM_{10} and $PM_{2.5}$ “capture-and-remove-by-sweeper” performance as well as the minimum “disturb-and deposit-elsewhere” performance of available street sweepers. Testing was undertaken for purposes of comparative assessment rather than establishing a pass/fail approach.

APPENDIX 'C'

PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test

The results of the findings for the street sweepers tested are summarized in Table No. 4. For the purpose of protecting the identity of all manufactured models, involved in the testing, the sweepers have been labelled as Sweeper 1, 2, 3 etc.

Table No. 4 - PM_{10} and $PM_{2.5}$ Efficiency Findings

Particulate Matter Criteria		Sweeper 1 Regenerative -air	Sweeper 2 Regenerative -air *	Sweeper 3 Mechanical	Sweeper 4 Mechanical	Sweeper 5 Mechanical	Sweeper 6 Old vacuum *	Sweeper 7 Vacuum-assist	Sweeper 8 Vacuum-assist
Removal of Material from Surface Efficiency (%)		90.31%	65.11%	84.97%	81.27%	85.16%	64.53%	80.81%	90.16%
Deposit on Sidewalk Efficiency (%)		0.07%	N/A	0.18%	N/A	0.23%	N/A	0.09%	0.18%
PM_{10} Air Contamination	Maximum Concentration ($mg/m^3/kg$)	0.03	2.21	0.27	0.42	0.08	2.24	0.12	0.20
	Total Concentration ($mg/m^3/kg$)	10.35	529.80	45.57	144.86	18.54	971.04	10.15	45.33
$PM_{2.5}$ Air Contamination	Maximum Concentration ($mg/m^3/kg$)	0.01	1.36	0.05	0.24	0.02	1.37	0.04	0.03
	Total Concentration ($mg/m^3/kg$)	3.95	223.45	11.56	67.94	5.44	449.90	4.68	7.70

Note: All figures represent average test results for each sweeper
* Old models no longer manufactured

The overall test findings clearly demonstrate that Sweeper 1 (Regenerative-air model) achieved the highest efficiency performance in both PM_{10} and $PM_{2.5}$ in all three key criteria categories:

In addition to the Disco Yard testing, several mechanical street sweepers were visually observed and air contamination levels measured in the real world environment using LIDAR technology. LIDAR is an abbreviation for **LI**ght **D**etection **A**nd **R**anging technology, which is remote sensing equipment using emitting laser light pulses to measure the fine road dust's plume concentration and movement as the signals bounces back to a receiver. LIDAR equipment is provides the ability to track fine road dust (i.e. Total Suspended Particulates and Particulate Matter (PM_{10} and $PM_{2.5}$). Using this technology, mechanical street sweepers were observed agitating and disturbing into the air fine road dust during sweeping operations. Cross-sectional images of the plume of fine road dust generated by the mechanical sweepers were recorded with

the data showing that approximately 80% of PM_{10} stays below 2 metres (vertically) and stays within 10 metres (horizontally) during sweeping.
This regular occurrence of fine road dust being disturbed into the air could be virtually eliminated using a regenerative-air street sweeper, whose technology is designed to handle these situations.

After a full examination of all the test data compiled, staff conclude that a **92% combined surface and air removal efficiency** could be achieved with the use of a regenerative-air street sweeper. This would translate into an estimated **35%** improvement in PM_{10} content of ambient air citywide, if implementing a full fleet of regenerative-air street sweepers (i.e. complement of 50 sweepers).

APPENDIX ‘D’

Operational Performance Evaluation

In 2004, the City of Hamilton, Sweeper Advisory Committee circulated a questionnaire to evaluate the effectiveness of street sweepers currently in their fleet. Street sweeper operators were asked to complete the questionnaire and evaluate three types of sweepers. The sweepers evaluated were two mechanical vacuum-assist street sweepers (Sweeper 8- *similar to the one tested at Disco Yard* and Sweeper 9- *sweeper not part of any City testing*) and one regenerative-air street sweeper (Sweeper 1- *similar to the one tested at Disco Yard*). A total of 28 questionnaires were circulated to operational staff. The questionnaire included specific questions in the following three categories: equipment maintenance, operational performance and ergonomics. The staff scored the three types of street sweepers based on following rating categories: “do not meet expectations”, “meet expectations” or “exceeds expectations”. In addition, staff also provided comments on several open-ended questions. The results were compiled by the City of Hamilton and with their permission have allowed the City of Toronto to use and publish the information. The results are presented in Table No. 5.

Table No. 5 - Summary of City of Hamilton Questionnaire Results

Category	**Does Not Meet Expectations (%)**			**Meets and Exceeds Expectations (%)**			**No Answers Provided (%)**		
	Street Sweeper			**Street Sweeper**			**Street Sweeper**		
	9	**8 ***	**1 ***	**9**	**8 ***	**1 ***	**9**	**8 ***	**1 ***
Maintenance Issues	29	32	3	63	68	93	8	0	4
Operational Performance Issues	27	28	5	63	71	88	10	1	7
Ergonomic Issues	35	11	16	65	89	84	0	0	0

* Were tested at Disco Yard Facility

From the results in Table No. 5 it is evident that the regenerative-air street sweeper (Sweeper 1) clearly demonstrates that the technology is very reliable with minimum maintenance issues. The equipment also received favourable results on operational performance, a significant concern for Transportation Services’ Road Operation staff when using the equipment.

In addition to the City of Hamilton survey, the City of Toronto road operation supervisors, in 2004, were allowed to visit Hamilton and carry out a separate evaluation of the new technology street sweepers. The supervisors were allowed to sit in the cabs of the sweepers while operated by a City of Hamilton operator. Prior to that, a questionnaire was developed by City of Toronto staff to help evaluate and verify the City of Hamilton results and examine other operational, maintenance and ergonomic issues not covered under the City of Hamilton questionnaire.

Toronto staff evaluated Sweeper 1, a regenerative-air street sweeper, and Sweeper 3, a vacuum-assist street sweeper, both models having been tested at the Disco Yard facility. An overall assessment of the responses to the questionnaire clearly indicated that the regenerative-air street sweeper effectively met key operational requirements, such as:

- efficient leaf and heavy silt loading pick-up;
- efficient pick-up of large debris;
- ability to operate during wet conditions (rain);
- ability to operate below zero temperatures; and
- ability to operate in a dry dustless mode.