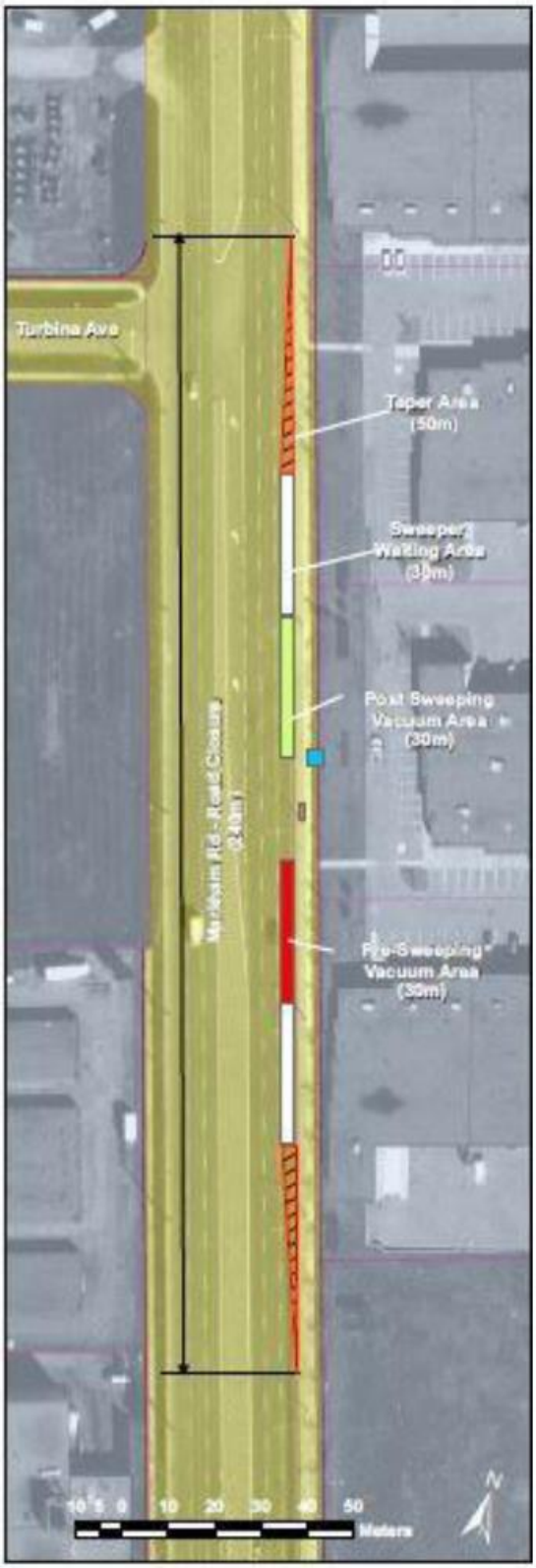
2014

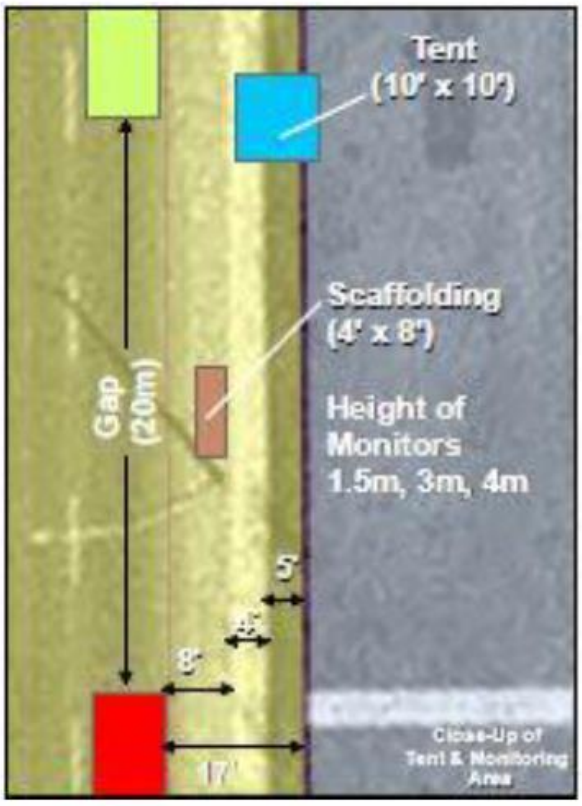
Street Sweeper Ambient Air Quality Monitoring Study

Summary Report

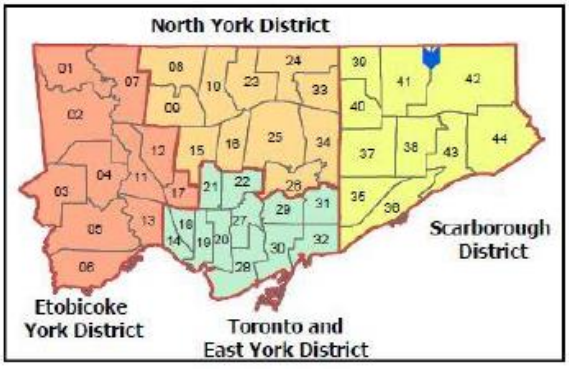
August, 2015

Toronto Transportation Services


Turbina Ave
Taper Area
(50m)
Sweeper
Waiting Area
(30m)
Post Sweeping
Vacuum Area
(30m)
Pre-Sweeping
Vacuum Area
(30m)
10 5 0 10 20 30 40 50
Meters
N



Street Sweeper Air Quality Monitoring Study - 2014
Road Closure Map
(Scarborough District - Markham Rd)



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These regenerative-air street sweepers have realized the removal of a significant amount of fine particulate matter from the City of Toronto's paved roads year-round. As part of the Clean Roads to Clean Air Program (CRCA) and the initial testing undertaken, in a controlled environment, the results have shown that regenerative-air street sweepers reduce airborne fine particulate matter, at street level, by at least 21%.

The results of the Study implemented in the real world environment show that the regenerative-air street sweeper reduce airborne fine particulate matter, at street level, by at least 27%.

Street Sweeper Ambient Air Quality Monitoring Study

Background Summary

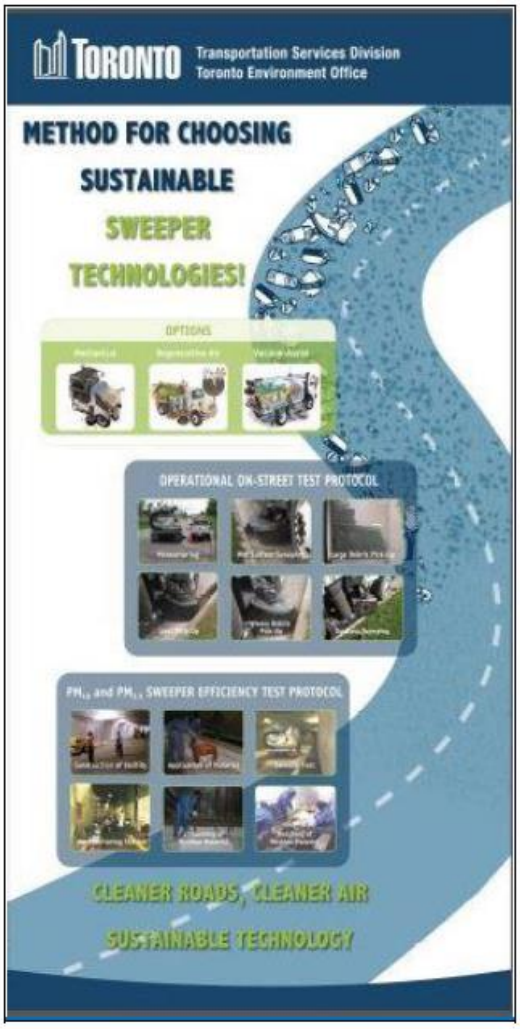
Initiated in 2003, Transportation Services' (TSD) Clean Roads Clean Air Program (CRCA) defined a process that made it possible to obtain quantitative results of a street sweeper's operational and PM_{10} and $PM_{2.5}$ efficiency and provided the justification for the City to proceed with the acquisition of 50 new regenerative-air street sweepers. These new sweepers have realized the removal of a significant amount of fine particulate matter (PM) from the City of Toronto's paved roads year-round. The new sweepers, in a controlled environment, were shown to reduce airborne fine particulate matter, at street level, by at least 21%. Test protocols were developed, along with efficiency criteria to evaluate the operational and particulate matter removal efficiency of various street sweeper technologies. The evaluation process provided a framework for continuous development of new operational practices and procedures, ensuring that the City's street sweeping service would be delivered in a safe, environmentally sustainable, efficient and effective manner.

The new sweepers have provided a means by which air quality could be improved, thereby directly benefiting the general health of City's residents, workers and visitors, and significantly reduce the number of cases of acute and chronic exposure to fine particulate matter. In addition, the sweepers helped in removing large quantities of toxic loads from the City's roads that would have been washed down into catch-basins and into the storm sewer system. By doing so the stormwater quality is improved, thereby reducing the cost of stormwater treatment.

In order to continue the process established in the CRCA Program based on continuous improvement in environmental performance, the 2014 Study evaluated whether these objectives were being met. The following is a summary of CRCA Program leading edge procurement process tied to the third party verification of environmental performance that was established:

- An innovative procurement process was developed and utilized to purchase the 50 new street sweepers based on the PM and operation performance. Typically, heavy equipment is procured using a Request For Quote which has to meet specifications and evaluated on price. The procurement was based on Request For Proposal process which used a base minimum specification, but also evaluated sweeper performance based on PM and operational criteria. In addition, maintenance and overall cost was objectively evaluated to determine the most cost effective sweeper in achieving PM efficiency and operational performance;
- In North America the street sweeper industry adopted the City of Toronto PM Efficiency and Operational Protocols and enhanced the design of two street sweeper technologies (Elgin and Schwarze) so that industry can meet the City of Toronto more stringent environmental performance requirements;
- **Canadian Environmental Technology Verification Program** under a license agreement with Environment Canada and Industry Canada to provide a mechanism for **third-party verification of environmental technology performance** claims and to facilitate successful technology commercialization. The Environmental Technology Verification Canada (ETV Canada) under the ETV Program adopted the City of Toronto PM Efficiency and Operational Testing Protocols and can provide separate Verification Certificates for air quality and operational performance of various street sweeper technologies based on the testing protocols.

TSD collaborated with a number of A,B,C and D's, provincial and federal government throughout the process which including: Fleet Services, Public Health Services, Legal Services, Toronto Water, Purchasing and Material Management Division, City of Hamilton, Ministry of Transportation, Environment Canada and Canadian Environment Technology Verification Program.



Purpose of Study

City Council on July 2005, adopted the report, entitled, *'PM10 and PM2.5 Efficient Street Sweepers for the City of Toronto (All Wards)'* requested staff to report back on the effectiveness of the above new regenerative-air street sweepers. More recently, the Auditor General requested a review of various equipment maintenance practices made the following recommendation to review the City's street sweeping performance measurement processes and where applicable develop appropriate measures. The process should measure the ongoing effectiveness of the City's street sweeping services in the area of air quality, tonnage of debris collected and equipment downtime information. In February 2014, the Street Sweeper Ambient Air Quality Monitoring Study (Study) was initiated.

Objective of Study

The objective of the Study was to assess the effectiveness of regenerative-air street sweepers in improving the ambient air quality by reducing the concentration levels of PM_{10} and $PM_{2.5}$ on City streets. The results of the Study can be used as a basis to modify service levels (frequency of sweeping), setting equipment and staff requirements and identifying operating and capital budget impacts. This Study was the monitoring component of the Divisional Program called *Clean Roads Clean Air* (CRCA) that was initiated back in 2003. The CRCA Program defined a process that made it possible to obtain quantitative results of a street sweeper's operational and PM_{10} and $PM_{2.5}$ efficiency performance and provided the justification for the City to proceed with the acquisition of 50 new regenerative-air street sweepers.

Project Description

In 2014, testing was undertaken as part of the Study to measure the performance of both a mechanical and regenerative-air street sweeper to obtain the following results:

- Ambient air quality concentrations, measured at nose-level, pre and post street sweeping;
- Dust concentration levels during sweeping operation; and
- Silt loading removal from the paved road surface pre and post sweeping.

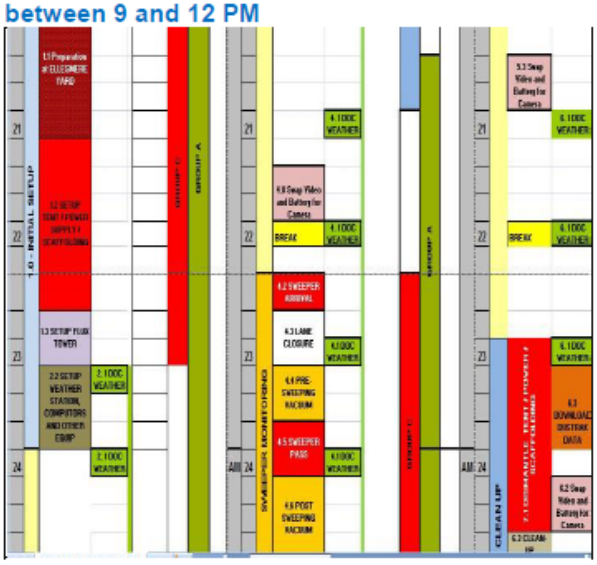
The Study was conducted on Markham Road, between McNicoll and Turbina Avenues. Stationary air monitors were used to measure the ambient air quality continuously for 48 hours each week for 3 consecutive weeks (air quality monitors were set at three different height levels). This monitoring sequence was undertaken to evaluate a mechanical sweeper in June 2014 and a regenerative-air sweeper in September 2014.

- *Study team was comprised of three groups, a total of 12 staff;*

- *Two groups (day and night shifts) were responsible to be on location working 3 consecutive 12 hour shifts for 3 consecutive weeks, under all environmental conditions;*
- *Third group assisted with the lane closure, camp site and monitor setup and dismantling and street sweeper test equipment;*

The testing attempted to replicate the silt loading conditions pre and post deployment of the regenerative-air street sweeper in order to determine the effectiveness of the sweeper technology in improving the ambient air quality. Prior to the acquisition of regenerative-air street sweepers in 2007 and 2008 the street sweeper complement consisted solely of mechanical street sweepers. The testing attempted to measure air quality in a real world environment, recognizing that many environmental conditions could not be controlled. This is in contrast to the City of Toronto's PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test protocol which was developed and used to control as many environmental conditions, in a closed environment, using a systematic, quantifiable and objective approach to evaluate and ultimately determine the most efficient PM_{10} and $PM_{2.5}$ street sweeper technology.

Figure 1: An Example of Testing Schedule between 9 and 12 PM



In order replicate the original silt loading condition (pre deployment of regenerative-air street sweeper), three months prior to implementing the ambient air quality monitoring, the study area was swept once a week by a mechanical sweeper. Once Phase 1 of the study was completed in June 2014, evaluating the ambient air quality of the mechanical street sweeper, the pavement surface then needed to be prepared for the testing of the regenerative-air street sweeper. A regenerative-air street sweeper swept the Markham Road once a week for a period of two months. Phase 2 of the study was undertaken in September of 2014. All sweepers were evaluated and repaired as required and attained optimal operating condition as appropriate for the respective age of the street sweeper. A full maintenance check was undertaken for each of the sweepers prior to the commencement of the monitoring test.

Collaboration and Consultation

The Operational Planning and Policy Unit staff person was the main lead of this monitoring Study and was responsible for, defining the scope of the study, development of the testing protocol, establishing a budget, staffing and equipment requirements, securing funding and staff resources, identifying all health and safety requirements, training and implementation of the study. In addition, collaboration and consultation took place throughout the study process and involved the many internal and external stakeholders.

Key to the success of this study is the collaboration and consultation throughout the process with the following stakeholders: TSD's road operation, Fleet Services (FS) and Environment and Energy (E&E) Division. The following examples illustrate this aspect:

- E&E's Senior Air Quality Specialist was consulted on the development of the ambient air testing protocol to test the PM efficiency of street sweepers in a real world setting and ensure that sound scientific process was being used and would yield objective and quantifiable results;
- The study required a commitment of FS senior staff and maintenance staff. FS were consulted on the testing protocol and were tasked to ensuring that the fleet of street sweepers required for the testing were in optimal operating condition prior to and during the testing. This included evaluating the street sweepers and performing regular maintenance and any unforeseen repairs were expedited as soon as possible;
- *The greatest contributors to the study, aside from the project management, was secured from the*

Scarborough Road Operation District which included the contribution of staff, equipment and funding for the project. Operation staff demonstrated absolute commitment and exemplified the 24/7 motto of the organization;

- In addition, to the project manager for the study, two other OP&P staff were required to make this Study a success, especially in the acquisition of the equipment and securing all the necessary approvals from other groups to ensure that no other activity occurred during the testing. Other groups within TIMS facilitated by providing equipment.

Other staff that were consulted and provided assistance at various stages of the Study process were IT and Health and Safety (H&S) staff; various equipment vendors and Divisional staff from traffic operations, traffic planning and right-of-way. The following examples illustrate this aspect:

- Technical issues surrounding hardware, software requirements and compatibility with all electronic equipment including computer, air quality monitors, video and communication equipment were dealt with consultation with IT staff and private vendors;
- H&S staff were consulted on all traffic and operational safety issues, including safe operating procedures of all equipment and all personal protection equipment;
- PM_{10} and $PM_{2.5,}$ at certain concentration, are considered toxic substances under the Canadian Environmental Protection Act and as a result each of the testing tasks were evaluated for exposure to fine particulate matter and all personal protection equipment were identified and provided;
- *H&S staff assisted by providing fall arrest training to staff prior to the commencement of the Study; and*
- Vendors of equipment provided technical training of the air quality monitoring equipment.

Lastly, a Study of this magnitude would be considered beyond the technical and resource capability of TSD and/or Corporation. The successful implementation of the Study is an example of OP&P's capability to foster working relationships among Divisions and addresses not only Divisional objectives but align with Corporate and Council directives. It also demonstrates the project management competency and technical expertise that exists within OP&P and the other functional groups of TSD. By undertaking the study, the collaboration fostered knowledge transfer with respect to street sweeper performance issues which ultimately enhances the effectiveness of the management of the street sweeper fleet.

Outcome of Study

Upon completing the 2014 Study, a number of statistical analyses were performed on the collected data and comparing the ambient air quality concentration levels prior to, during and after street sweeping for both the mechanical and regenerative-air street sweepers. In addition, silt loading data was calculated prior to and after street sweeping to determine the removal efficiency for each sweeper. The measured concentration levels and removal efficiency quantities were averaged for all three days of testing for each street sweeper technology. Tables 1, 2 and 3 below, show the results of the Study for the respective street sweepers.

The final results clearly demonstrate that the regenerative-air street sweeper has a removal efficiency that is almost three times higher when compared to the mechanical sweeper (i.e., 66% versus 25%). The test results also revealed that the regenerative-air street sweeper has on average 90% and 89% greater entrainment efficiency (i.e., suspended particulates in the air) for PM_{10} and $PM_{2.5,}$ respectively, during the actual sweeping operations when compared to the mechanical sweeper.

Table 1: Mechanical Street Sweeper Ambient Air Quality Results

Efficiency Criteria	Before Street Sweeping	After Street Sweeping	Percentage Difference Pre vs Post Sweeping
Removal Efficiency of Silt Loading (kg)	3.121	2.312	25.9%
Maximum PM_{10} Concentration (mg/m^3)	0.259	0.228	12.0%
Maximum $PM_{2.5}$ Concentration (mg/m^3)	0.210	0.230	-9.5%
Average PM_{10} Concentration (mg/m^3)	0.021	0.013	38.1%
Average $PM_{2.5}$ Concentration (mg/m^3)	0.020	0.013	35.0%

Table 2: Regenerative-air Street Sweeper Ambient Air Quality Results

Efficiency Criteria	Before Street Sweeping	After Street Sweeping	Percentage Difference Pre vs Post Sweeping
Removal Efficiency of Silt Loading (kg)	10.345	3.552	66.0%
Maximum PM_{10} Concentration (mg/m^3)	0.319	0.156	51.1%
Maximum $PM_{2.5}$ Concentration (mg/m^3)	0.331	0.177	46.5%
Average PM_{10} Concentration (mg/m^3)	0.028	0.018	35.7%
Average $PM_{2.5}$ Concentration (mg/m^3)	0.026	0.016	38.5%

Table 3: Ambient Air Quality Results During Street Sweeping Test

Efficiency Criteria	During Street Sweeping Test		
	Mechanical Street Sweeper	Regenerative-air Street Sweeper	Entrainment Efficiency Difference
Maximum PM_{10} Concentration [(mg/m^3)]/kg	0.139	0.005	96.4%
Maximum $PM_{2.5}$ Concentration [(mg/m^3)]/kg	0.112	0.004	96.4%
Total PM_{10} Concentration [(mg/m^3)]/kg	3.028	0.496	83.6%
Total $PM_{2.5}$ Concentration [(mg/m^3)]/kg	2.768	0.463	77.2%
Average PM_{10} Concentration [(mg/m^3)]/kg	0.030	0.003	90.0%
Average $PM_{2.5}$ Concentration [(mg/m^3)]/kg	0.027	0.003	88.9%

What was inconclusive from the test were the results related to the average concentration levels for PM_{10} and $PM_{2.5}$ for pre and post sweeping (see Tables 1 & 2). The average ambient air concentration results were in the 35% to 38% range for both sweepers. However, the maximum ambient air concentrations for PM_{10} and $PM_{2.5}$ measured during pre and post street sweeping for regenerative-air street sweeper were four to five time less than the mechanical street sweeper after sweeping the road surface.

As previously mentioned, implementing an ambient air quality study in a real world environment can pose many challenges, including not being able to control environmental factors that can affect the air quality concentrations levels measured during testing. For example, prior to and during the testing of the mechanical street sweeper a number of significant rain events occurred which caused much of the silt loading on the road to be flushed down into the catch basins. This resulted in the overall pre and post test average ambient air concentration readings for the mechanical street sweeper to appear somewhat better than would otherwise have been the case; thus no comparable difference was observed. In addition, it should also be pointed out that the regenerative-air street sweeper was at the

end of its lifecycle, and its water suppression system malfunctioned and so did one of its gutter brooms. Despite all the challenges experienced by the regenerative-air street sweeper, it still out-performed the mechanical sweeper.

The results of the study implemented in the real world environment show that the regenerative-air street sweeper reduced airborne fine particulate matter, at street level, ***by at least 27%.***

Benefits

These regenerative-air street sweepers have realized the removal of a significant amount of fine particulate matter from the City of Toronto's paved roads year-round.

Continuing to purchase street sweepers based on highest environmental and operational performance criteria, with no limitations on the type of technology, will ensure that the City always operates streets sweepers that remove the most silt loading and have the highest entrainment efficiency and continue contribute to improved air quality within the City's rights-of-way.

An evaluation of street sweeper environmental performance results in many achievable benefits for the community, in that:

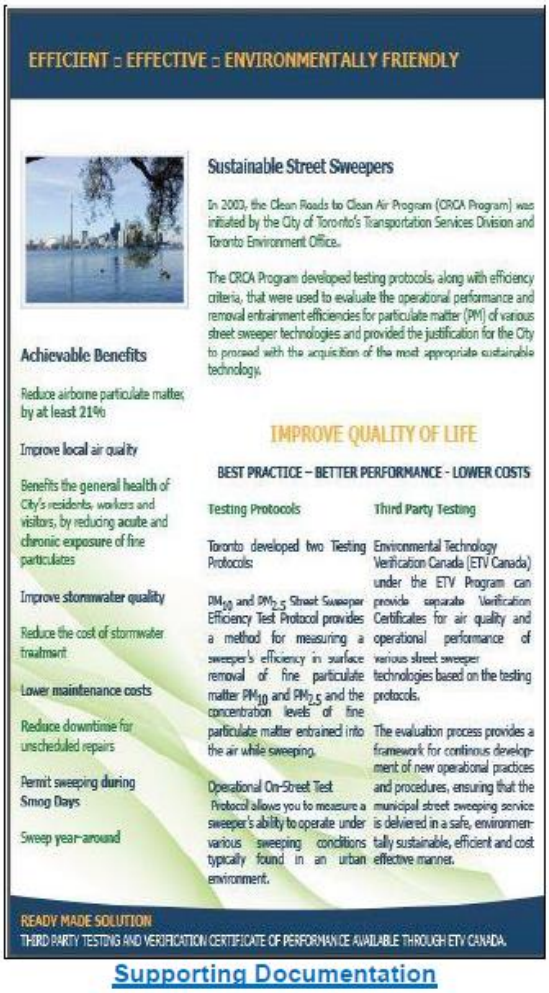
- it reduces airborne particulate matter which contributes to GHG emissions;
- it improves **local** air quality and benefits the **general health** of City's residents, workers and visitors, by reducing **acute** and **chronic exposure** of fine particulates;
- it removes toxic loads from City streets and ensure that particulate matter, that is typically washed down into catch-basins and into the storm sewer system, will be significantly reduced and results in improved stormwater quality and a reduction in the cost of stormwater treatment.
- improves **stormwater quality and** reduces the cost of stormwater treatment; and
- allows sweeping **during Smog Days and permits** sweeping **year-around.**

The Study and CRCA Program meet the City of Toronto's Air Climate Change, Clean Air and Sustainable Energy Action Plan both mitigation and adaptation criteria. Addresses mitigation by reducing the particulate matter that is entrained in the air and contributes to the formation of Smog. It is adaptive in that it prevents particulate matter and other debris from being flushed down the catchbasin and/or accumulating in natural water systems and potentially causing flooding during extreme rain events.

Conclusion

The Study provides a real world validation and justifies

- *the continued use of the testing protocols that were developed as part of the CRCA Program as the basis for evaluating the performance of street sweepers;*
- *requiring third party validation of street sweeper PM and operational performance under the ETV Program be continued; and*
- *the procurement of street sweepers be done through a RFP process.*



Supporting Documentation

For additional information on the implementation, results and background information on the Clean Roads to Clean Air Program, please see the enclosed prospectus and following websites for supporting documentation:

- Clean Roads to Clean Air Program;
- New Street Sweepers Will Improve Air Quality;
- City of Toronto's PM_{10} and $PM_{2.5}$ Street Sweeper Efficiency Test Protocol;
- City of Toronto's Operational On-Street Test Protocol;
- ETV Canada Street Sweeper Verification of Both Test Protocols;
- ETV Certificate of PM Performance based on City of Toronto Protocols-Elgin Crosswind;
- ETV Certificate of PM Performance based on City of Toronto Protocols-Tymco DST-6;
- Change is in the Air Climate Change, Clean Air and Sustainable Energy Action Plan, pg 12;