Clean Roads to Clean Air Program

2007 APWA Public Works Congress & Exposition

TORONTO Transportation Services Div. Toronto Environment Office

Clean Roads To Clean Air Program

Presenter

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Acknowledgement

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Air Quality Improvements Branch
Toronto Environment Office

Clean Roads To Clean Air Program

Are you struggling to achieve the following with your street sweeping equipment?

- Cleaner Roads;
- Cleaner Air – **Reduce Smog**;
- Cleaner Stormwater;
- Year Round Performance;
- Less Downtime; and
- Low Maintenance

If you answered YES to any of these, this presentation will help you achieve these goals!!

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Clean Roads To Clean Air Program

Agenda

- Background
- Internal and External Stakeholders
- Air Quality in Toronto
- What and Where is Particulate Matter
- Early Air Quality Modeling Results
- Street Monitoring Fine Road Dust
- LIDAR Test
- Clean Roads to Clean Air Program
  - Objectives
  - Key Elements
  - Toronto Protocol Development
  - Toronto PM Street Sweeper Efficiency Test Protocol and Criteria
  - PM Street Sweeper Efficiency Test

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Clean Roads To Clean Air Program

Agenda Cont'd

- PM Street Sweeper Efficiency Test Results
  - Comprehensive Evaluation
  - Maintenance Review
  - Operational On-Street Test
  - Performance Evaluation
- Stormwater Quality Evaluation
- Outcomes
  - Recommendation
  - 2005 Street Sweeper RFP
- Results and Benefits
- Municipal Requirement - Third Party Testing
- Enhancement to CRCA Program
  - Best Practices
  - 2008 Street Sweeper Monitoring Study

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Background

- **Toronto air quality preliminary model results indicate that a major local source of fine particulate matter (PM_{10}) is attributable to fine road dust;**
- **New street sweeper technology were reportedly capable of removing at least 80% of fine road dust;**
- **An 80% removal of fine road dust (PM_{10}) could result in 25%-30% improvement in the City's PM_{10} air quality;**
- **Auditor General identified sweepers as a high replacement priority for the organization;**
- **Sweeper fleet experiencing increased downtime for unscheduled repairs; and**
- **Toronto's Wet Weather Flow Master Plan identified street sweeping as a Source Control measure**

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Internal and External Stakeholders

Internal Stakeholders

Transportation Services Division
Toronto Environment Office
Fleet Services
Toronto Public Health
Occupational Health and Safety
Purchasing Services
Legal Services

External Stakeholder

City of Hamilton
Environment Canada

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Air Quality in Toronto

- PM_{10} and $PM_{2.5}$ levels in Toronto routinely **exceed** the acceptable Provincial AAQC and CWS values
- Both PM_{10} and $PM_{2.5}$ are **significant** health concerns and year round health hazard especially at **"nose-level"** on City's arterial roads
- 1,200 premature deaths attributable to **chronic exposure** to $PM_{2.5}$
- 180 premature deaths attributable to **acute exposure** to PM_{10}
- Fine particulates cause **respiratory** and **cardiovascular** problems

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What is Particulate Matter

- The major source of PM_{10} in Toronto is **an invisible fraction of "Fine Road Dust"**;
- Particulate Matter (PM) + Ozone = **Smog**;
- **"Fine Road Dust" comes from tire wear, asphalt wear, clutch and brake wear**;
- PM_{10} was identified as a **"Toxic" substance** in May 2000 by the Canadian Ministers of Health and Minister of Environment (under Canadian Environmental Protection Agency);
- **Inhalable** particulate matter (IP or PM_{10})
- **Respirable** particulate matter (RP or $PM_{2.5}$)

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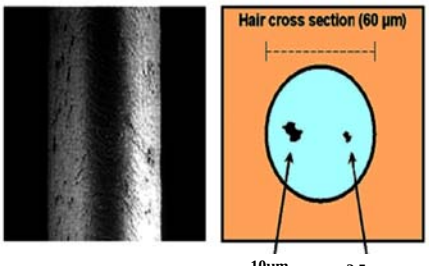
What is Particulate Matter



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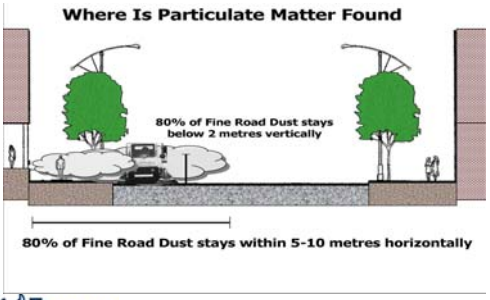
Where is Particulate Matter



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Toronto's Reality

City of Toronto
Mechanical Street Sweeper

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Early Air Quality Modelling Results

- New street sweeper technology such as: regenerative air, vacuums assist street sweepers are currently available and are reportedly capable of removing at least 80% of fine road dust (PM_{10});
- Modelling suggested that an 80% removal of fine road dust (PM_{10}) will provide 25%-30% improvement in the City's PM_{10} air quality and even greater improvement is expected for pedestrians and cyclists on the City's arterial roads.

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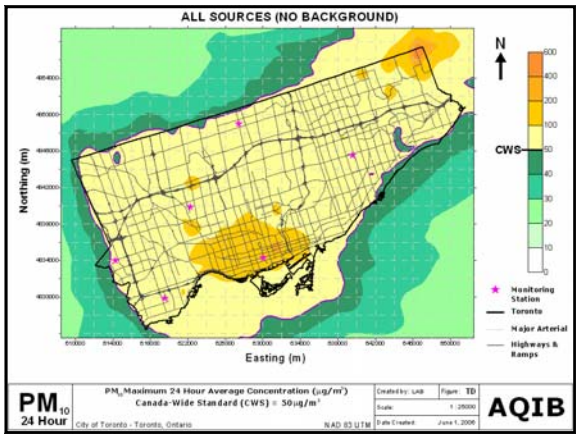

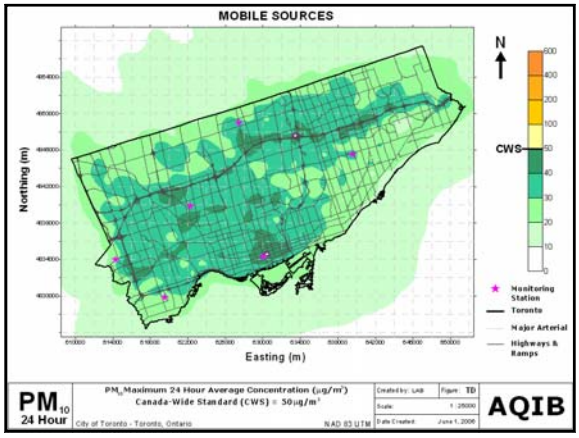

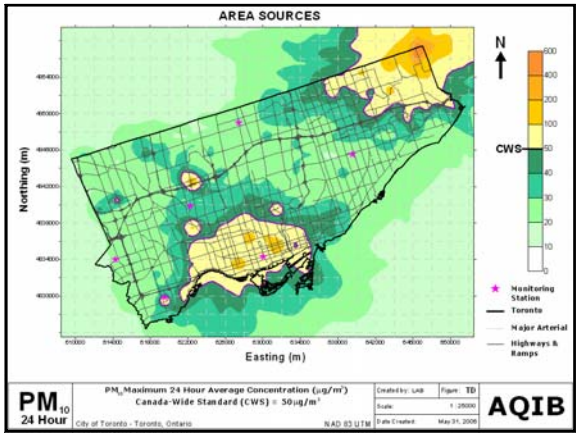

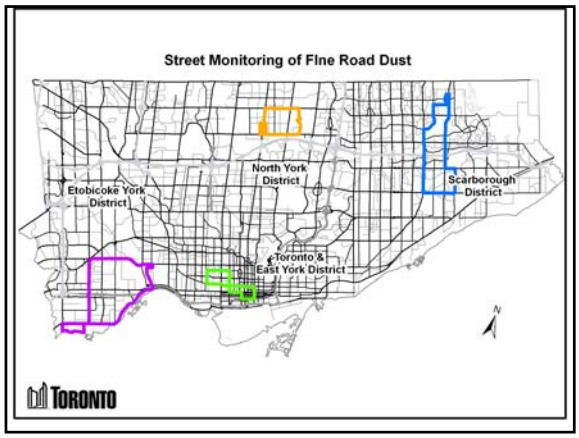

Street Monitoring Fine Road Dust

Objective

Obtain real-time Fine Particulate Matter, PM_{10} and $PM_{2.5}$ measurements in downtown Toronto to determine the street level concentrations to which motorists, cyclists and pedestrians are exposed.

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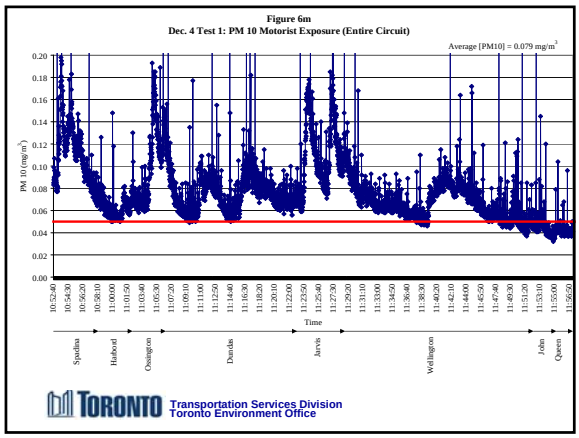

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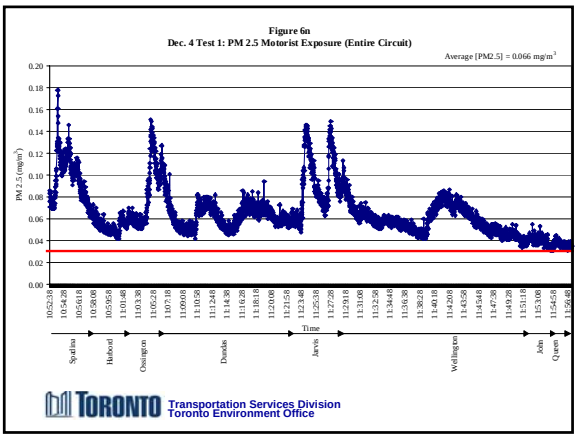

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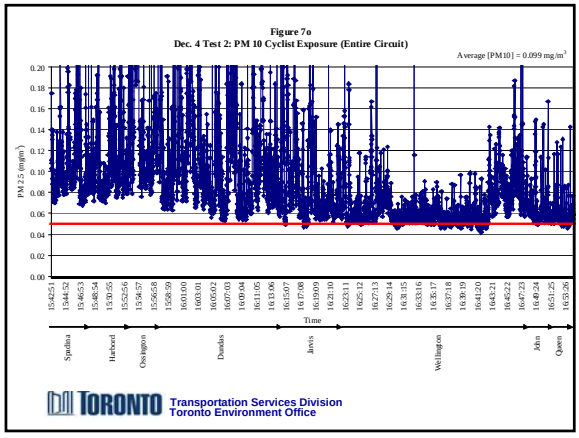

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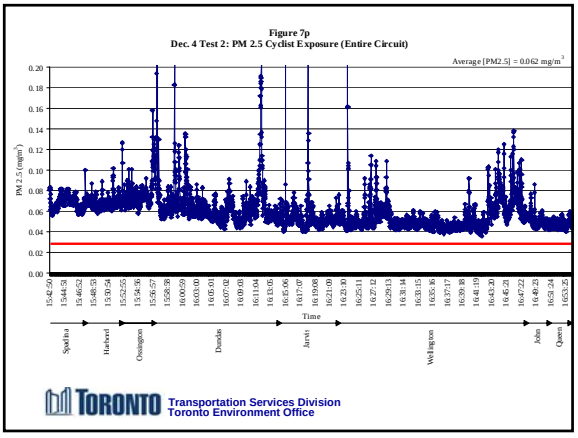

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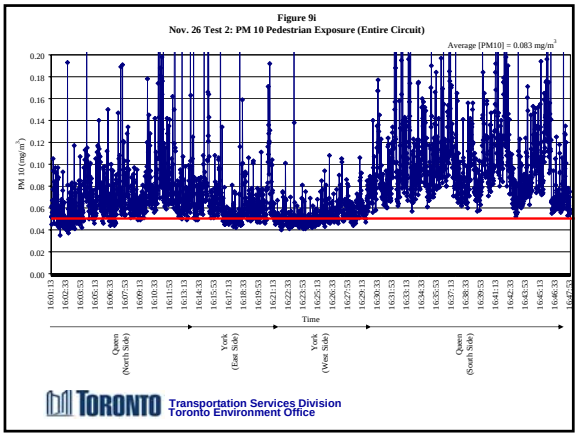

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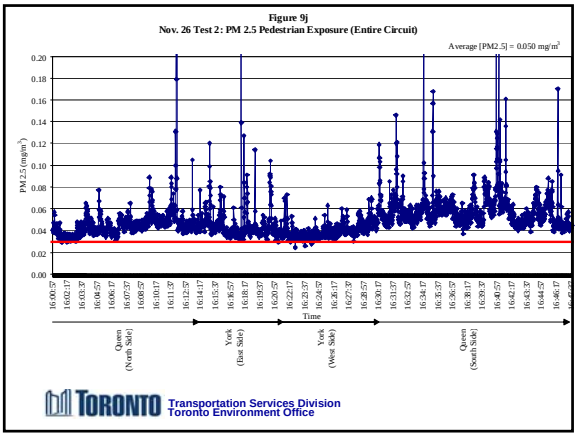

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Street Monitoring Fine Road Dust

Findings

- Toronto has an **air quality problem** related to Fine Road Dust (PM_{10} & $PM_{2.5}$);
- Daytime Street Levels of PM **exceed** Ambient Air Quality Criteria (AAQC) all Day;
- Problem varies with **various factors**:
  - Sweeping Frequency
  - Traffic Volumes
  - Type of Vehicular Traffic
  - Land Use
  - Time of Day
  - Weather;
- Confirms the need to **assess the potential** of "New Technology" Street Sweepers in reducing the concentration below AAQC levels;

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Street Monitoring Fine Road Dust

Future Work

- Continue **Monitoring Fine Road Dust Concentrations** (Mobile and Stationary) and compare old and new technology street sweeper effectiveness;
- Investigate the **relationship between** Street Design and Building Configurations and Concentrations of Fine Road Dust;

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LIDAR Test

What is LIDAR

LIDAR – **Light Detection And Ranging** technology, 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

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LIDAR Test

Purpose of LIDAR Testing

- Test whether we can use LIDAR as a **tool** to evaluate street sweeping activity;
- Obtain visual records and air contamination levels of various street sweepers technology under a **number of operational conditions**;
- LIDAR equipment **provides the ability** to track Fine Road Dust (Fine Particulate Matter, PM_{10}, $PM_{2.5}$) from City roads **under real conditions**;

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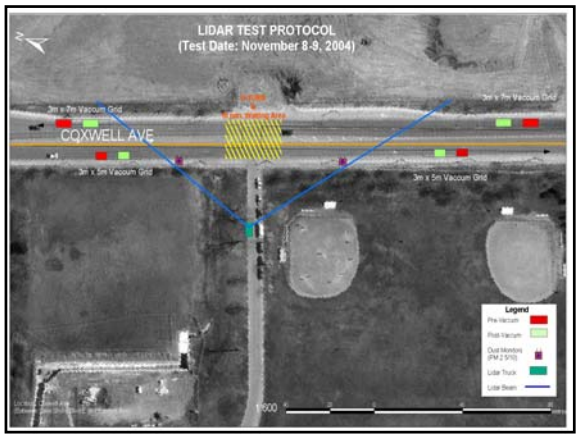
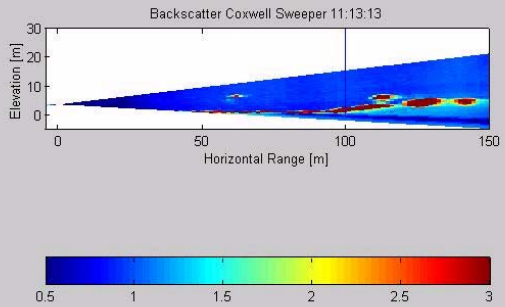
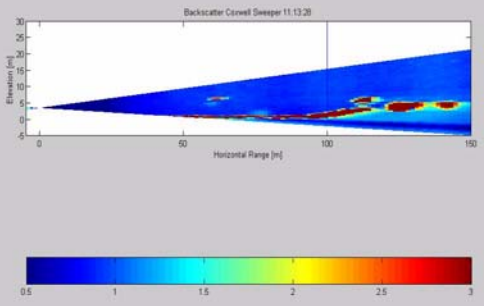


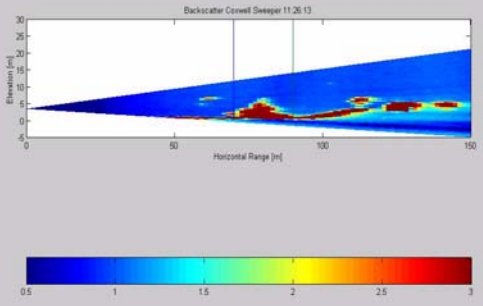
Coxwell Ave.- Background Condition 11:13:13



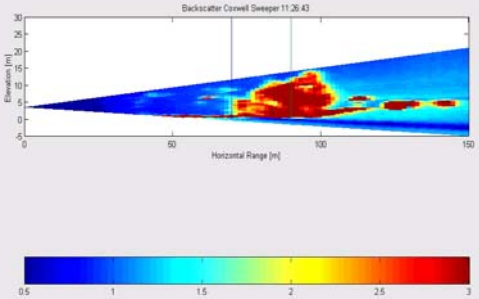
Car Travels North in East Curb Lane 11:13:28



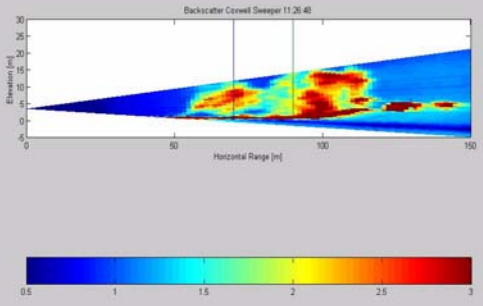
Mechanical Sweeper Travels North in East Curb Lane 11:26:13



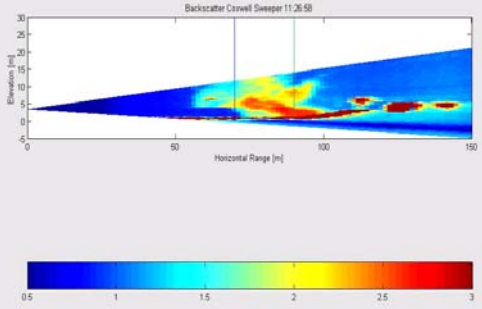
Mechanical Sweeper Travels North in East Curb Lane 11:26:43



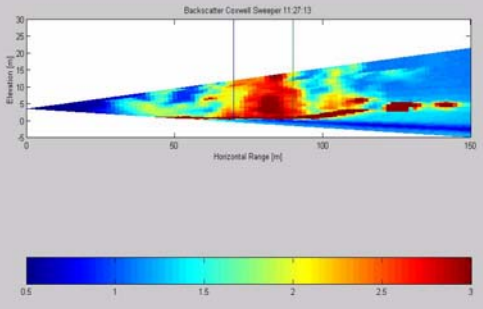
Mechanical Sweeper Travels North in East Curb Lane 11:26:48



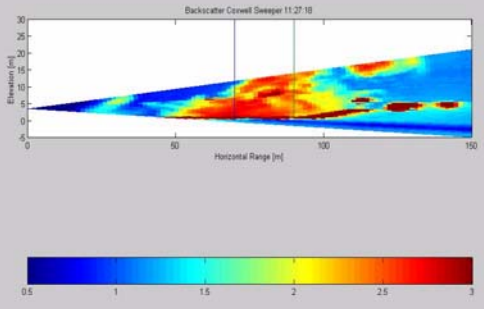
Mechanical Sweeper Travels North in East Curb Lane 11:26:58



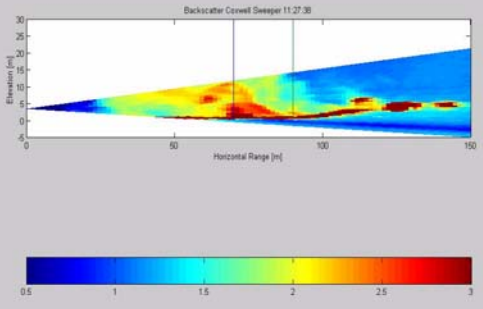
Mechanical Sweeper Travels South in Middle Lane 11:27:13



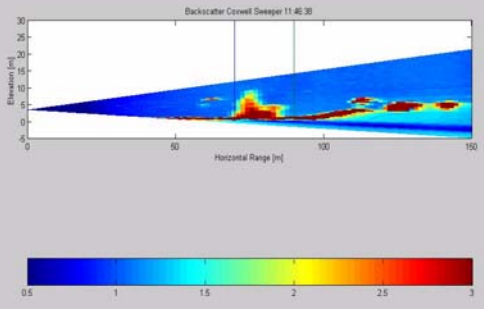
Mechanical Sweeper Travels South in Middle Lane 11:27:18



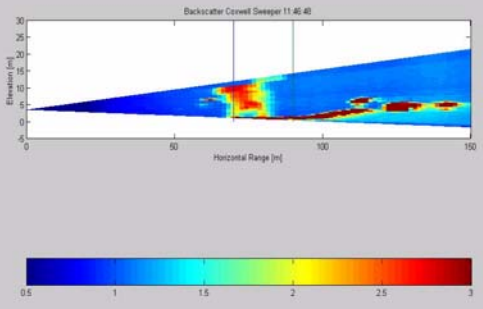
Mechanical Sweeper Travels South in Middle Lane 11:27:38



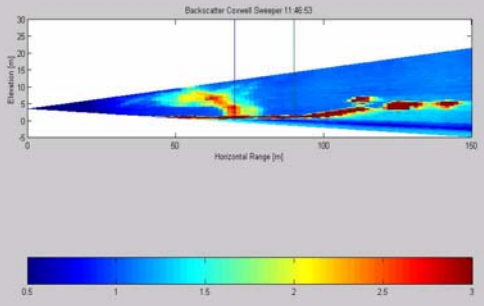
Car Travels North in East Curb Lane 11:46:38



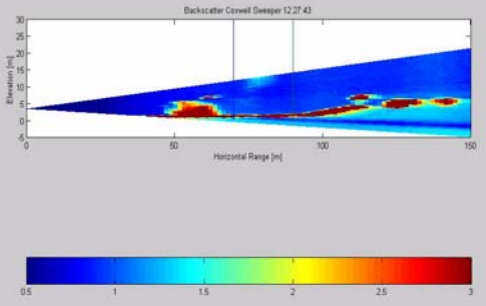
Car Travels North in East Curb Lane 11:46:48



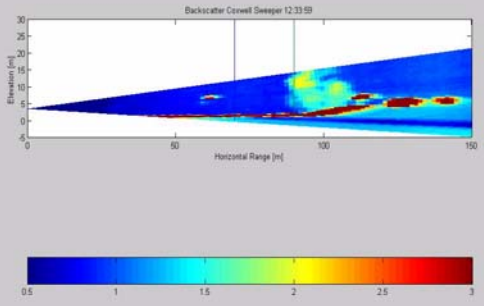
Car Travels North in East Curb Lane
11:46:53



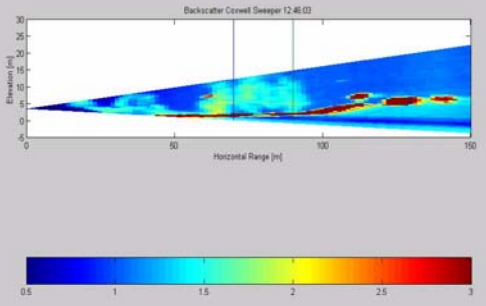
Car Travels South in Middle Lane
12:27:43



Wind Effects on Loosened Fine Dust
12:33:59



Wind Effects on Loosened Fine Dust
12:46:03



LIDAR Test

Key Findings

- Mechanical street sweepers disturb a significant amount of fine road dust into the air;
- Street sweeping activity in itself contributes to poor air quality;
- Sweeping disturbs road dust creating an even worse re-entrainment problem;
- 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;

Objectives of the CRCA Program

- to deploy PM_{10} and $PM_{2.5}$ efficient street sweepers that are capable of regular sweeping plus removing fine particular matter (PM_{10} and $PM_{2.5}$) from the City's paved roads year round; and
- to deliver the city street sweeping service in a manner that would significantly contribute to improving overall human health, air and storm water quality

Key Elements of the CRCA Program

- Air quality model;
- Operational Performance;
- Maintenance and Downtime Costs;
- Protocols
  - Evaluate PM_{10} and $PM_{2.5}$ efficiency
  - Evaluate operational performance;
- Implemented several studies understanding the nose-level air quality and the relationship between air quality and street sweeping activity;
- Stormwater quality;
- Street sweepings management and disposal;
- Occupational Health and Safety review, handling and cleaning procedures;
- Monitoring air quality during street sweeping

Toronto Protocol Development

Early Concepts

- Rule 1186 was considered But Found Lacking
  - Used 97% sand plus 3% PM_{10} "paint filler"
  - Certified if 80% of either material captured
  - No water use limit and shrouds were allowed for dust suppression
  - Used Open ended tunnel and forced air concentrations
  - Used a pass/fail approach
- City of Toronto – Sweeper Requirements
  - Use Gutter Brooms, BUT No Shrouds
  - Controlled Speed (8-10km/h)
  - Use No water
  - Has Dustless capability

Toronto Protocol Development

Why Dustless

- The critical value of determining the **most effective PM sweeper** is its ability to operate without putting excessive PM_{10} & $PM_{2.5}$ into the air that we breathe.
- Reduce the exposure of cyclist, pedestrian and motorists using our right-of-ways
- Permits **sweeping during smog days** and reduces smog impacts on population

Why Waterless

- Capability of sweeping year-around
- Avoid toxic loads being washed down catchbasins that impact the stormwater quality and the cost of treatment

Toronto Protocol Development

Why Shroudless

- **Operational performance** affected (i.e. problem picking up leaves, large debris);
- Shrouds are too easily and frequently **damaged**;
- Damaged shrouds **affects** removal and entrainment efficiency;
- **Leaves** a stream of silt debris next to the curb;

Toronto Protocol Development

General Test Concepts

- Controllable and Replicable Conditions Test
- Use Average of Three Tests
- Use Manufacture's recommended speed or 8–10 km/h if absent
- Pre-Vacuum Test Surface
- Known Quantity of Test Material Applied (PM_{10} Only)
- Pre and Post-Test Weight of Sweeper
- Post-Vacuum Test Surface
- Measure Removal & Entrianment Efficiency
- Not a Pass/Fail Approach

Toronto Protocol Development

Test Track (typifies a Toronto worst case scenario)

- aged asphalt with cracks & potholes
- curbs are essential
- include sidewalks in the Test Track

Test Material

- 270 kg of Test Material
- 100% Camel White - dry ground Lime Stone - marble ($CaCO_3$)
- median diameter = 3 microns (good for PM_{10} & $PM_{2.5}$)

Meteorology

- no precipitation in previous 36 hours
- wind speeds must be below 8 km/h
- track **MUST be dry**, relative & absolute humidity **MUST be low**

Toronto Protocol Development

Vacuuming and Spreading

- Test Strips were separated into twelve quandrants for the spreading of the test material;
- Test track was divided into eight quandrants that were vacuumed and evaluated as separate areas;
  - Four quandrants for the inside of the test track
  - Two quandrants for the sidewalk portion of the test track
  - Two quandrants, outside portion of the test track

Monitoring

- Used eight monitors – four PM_{10} and four $PM_{2.5}$ with two PM_{10} and two $PM_{2.5}$ monitors in the centre of the track operated 20 hours/day

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PM_{10} & $PM_{2.5}$ Street Sweeper Efficiency Test Protocol

The protocol establishes a method to gauge the year round efficiency of street sweepers for their removal of PM_{10} and $PM_{2.5}$ from typical Toronto urban streets and their ability to limit the amount of PM_{10} entrained into the air during the sweeping process.

Two key methods used in the evaluation of the street sweepers:

- how much material was picked up/left behind by the street sweeper and
- how much material was entrained by the street sweeper

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PM_{10} & $PM_{2.5}$ Street Sweeper Efficiency Test Protocol

PM Criteria and Thresholds

- Pick-up Removal Efficiency (%) **More than 90%**
- Deposit on Sidewalk Efficiency (%) **Less than 0.08%**
- Air Contamination PM_{10}
  - Maximum Concentration **Less than 0.08 mg/m³/kg**
  - Total Concentration **Less than 11 mg/m³/kg**
- Air Contamination $PM_{2.5}$
  - Maximum Concentration **Less than 0.02 mg/m³/kg**
  - Total Concentration **Less than 5.0 mg/m³/kg**

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Disco Yard Barn

Construction Crew

Monitoring Area

Loading of Test Material in Spreader

Application of Test Materials

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Supply Storage and Silt Loading Material Weighing Area

Resting Area

Weighing Area

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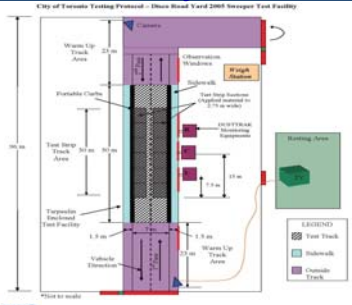
Enclosed Wash Bay / Dump Site

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



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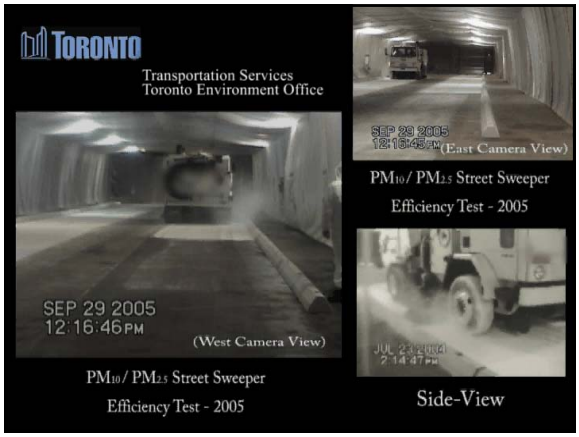
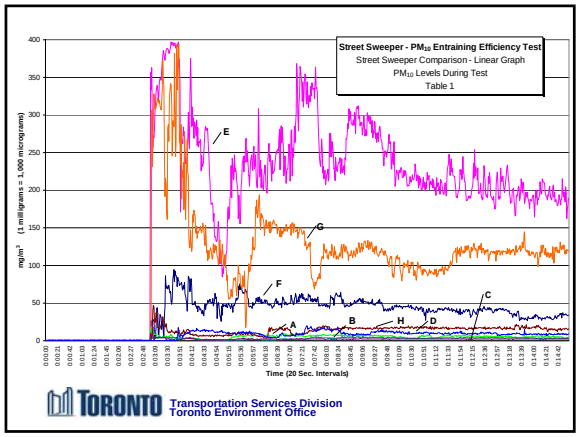
PM_{10} & $PM_{2.5}$ Street Sweeper Efficiency Test


TORONTO
Transportation Services
Toronto Environment Office
SEP 29 2005
12:16:46PM
(West Camera View)
PM10 / PM2.5 Street Sweeper
Efficiency Test - 2005
SEP 29 2005
12:16:45PM
(East Camera View)
PM10 / PM2.5 Street Sweeper
Efficiency Test - 2005
Side-View


TORONTO
Transportation Services
Toronto Environment Office
1:03:19PM
JUL 22 2004
Post Tunnel Condition
Washing Sweeper
Post Tunnel
Clean-Up


Street Sweeper - PM10 Entraining Efficiency Test
Street Sweeper Comparison - Linear Graph
PM10 Levels During Test
Table 1
mg/m3 (1 milligrams = 1,000 micrograms)
Time (20 Sec. Intervals)
E
G
F
C
B
H
D
A
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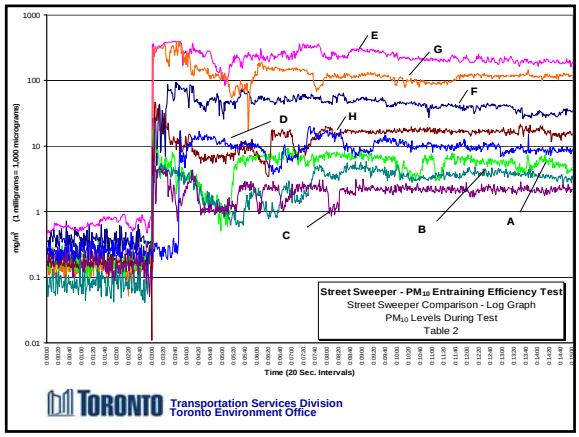
Street Sweeper - PM10 Entraining Efficiency Test
Street Sweeper Comparison - Log Graph
PM10 Levels During Test
Table 2
mg/m3 (1 milligrams = 1,000 micrograms)
Time (20 Sec. Intervals)
E
G
F
D
H
C
B
A
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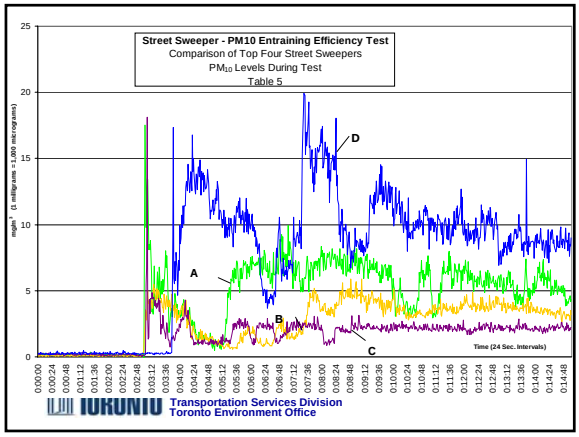
Street Sweeper - PM10 Entraining Efficiency Test
Comparison of Top Four Street Sweepers
PM10 Levels During Test
Table 5
mg/m3 (1 milligrams = 1,000 micrograms)
Time (24 Sec. Intervals)
D
A
B
C
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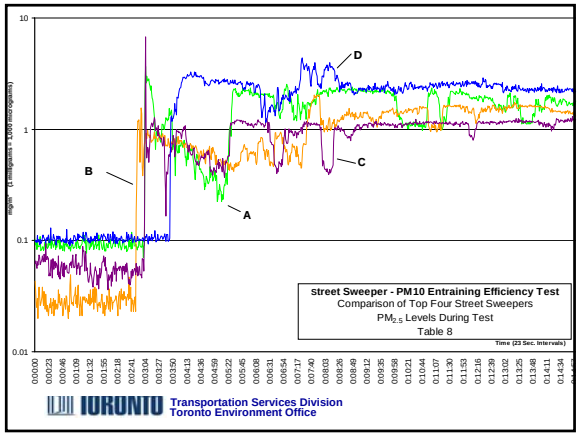
Street Sweeper - PM10 Entraining Efficiency Test
Comparison of Top Four Street Sweepers
PM2.5 Levels During Test
Table 8
Time (23 Sec. Intervals)
D
B
C
A
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PM_{10} & $PM_{2.5}$ Street Sweeper Efficiency Test Results

Top Four Street Sweepers – Test Results

Sweeper Company's Name		A	B	C	D
Street Sweeper Technology		Mechanical	Regenerative-Air	Vacuum-Assist	Vacuum-Assist
PM10 Criteria	Unit	Avg. of All Test Dates	Avg. of All Test Dates	7/24/2004	Avg. of All Test Dates
Removal Efficiency		85.16%	90.31%	80.81%	90.16%
% Sidewalk Efficiency		0.23%	0.07%	0.09%	0.18%
Air Contamination PM_{10} Maximum Concentration	$(mg/m^3)/kg$	0.08	0.03	0.08	0.20
Air Contamination PM_{10} Total Concentration	$(mg/m^3)/kg$	18.54	10.35	7.01	45.33
Air Contamination $PM_{2.5}$ Maximum Concentration	$(mg/m^3)/kg$	0.02	0.01	0.03	0.03
Air Contamination $PM_{2.5}$ Total Concentration	$(mg/m^3)/kg$	5.44	3.95	3.24	7.70

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Emission Comparison Mechanical VS Regenerative-Air

Street Company's Name	B	A	F
Street Sweeper Technology	Regenerative-Air	Mechanical	Mechanical
% of PM10 in Silt Loading	3%	3%	3%
Estimated Quantity of PM_{10} in Silt Loading Area 1 South District per month (kg)	19,132.10	19,132.10	19,132.10
Quantity of PM_{10} Deposited on the Sidewalk Area 1 South District per month (kg)	13.39	44.00	na
Quantity of PM_{10} Left Behind on Road Surface Area 1 South District per month	1,853.90	2,839.20	3,583.44
Comparison of Sweeper B and Sweeper A Quantity of additional PM_{10} left behind by Sweeper A (kg)		+985.30	
Comparison of Sweeper B and Sweeper F Quantity of additional PM_{10} left behind by Sweeper F (kg)			+1,729.54

Note: Average debris hauled over three month period April-June is 637,736.66 kilograms

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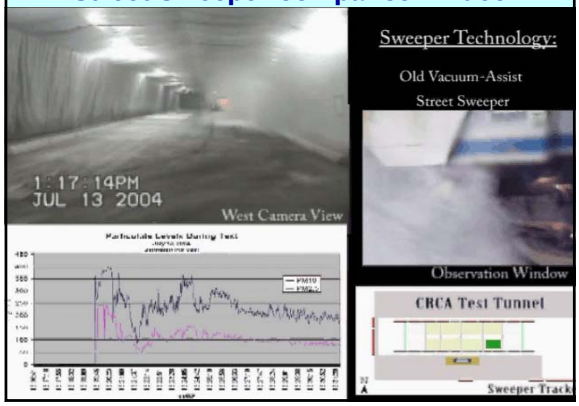
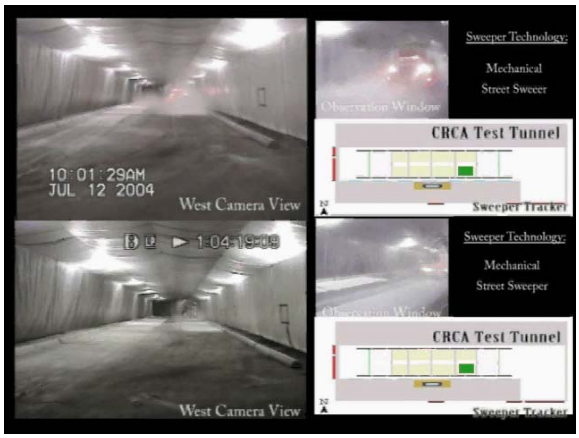
Street Sweeper Comparison Video





Maintenance Review

- Toronto staff reviewed the maintenance cost of a number of different street sweeper technologies that are operated in-house and through contracted services.
- Toronto staff obtained and reviewed the maintenance costs of different street sweeper technologies from several other municipalities.

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Operational On-Street Test

Key **operational requirements** evaluated:

- **Wet road surface** condition pick-up efficiency;
- **Maneuverability** around parked cars pick-up efficiency;
- **Leaf** pick-up efficiency;
- **Large debris** pick-up efficiency;
- **Heavy silt** loading pick-up efficiency; and
- Operate sweeper **without gutter brooms** pick-up efficiency

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Operational On-Street Test

Summary of Findings

Operational Requirements	Pick-up Efficiency (%) Mechanical	Pick-up Efficiency (%) Regenerative-air
Maneuverability	16%	36%
Pick-up Large Debris	90%	93%
Leaf Removal	93%	97%
Heavy Silt Loading	95%	98%
Sweeping During Wet Conditions	62%	89%
Dustless Sweeping (without gutter brooms)	n/a	87%

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Operational On-Street Test

[Operational On-Street Test](#)
(vacuuming to collect residue material)

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Performance Evaluation

Summary of Criteria Evaluated

Daily Maintenance by Operator - Cleaning hopper; Washing Sweeper; Fueling; Cleaning filters; and Cleaning Dust Trap

Daily Mechanical Maintenance - Replacing gutter brooms; shift pick-up head; replace pick-up head broom; replace water filter; and accessibility of parts

Parts Availability - Mock-up order of warranty and outside warranty parts

Operator Evaluation - visibility; ergonomics; comfort; noise in cab; dust in cab and safety features

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Stormwater Quality Evaluation

Study Objective

To assess the improvement of stormwater quality by street sweeping, one of the source controls included in the Toronto Wet Weather Flow Master Plan

Project implemented in 2004 and 2005, collaboration between Environment Canada, Toronto Water and Transportation Services Division

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Stormwater Quality Evaluation

Study Results

- new technology regenerative-air street sweepers provide the greatest environmental benefits by reducing the total mass or road deposited sediment after sweeping and dissolved metals in runoff;
- Key for street sweeping to be effective source control the following measures must be considered:
  - Sweep prior to rainfall and often as practical;
  - Areas with high level of pollution (such as arterial roads and industrial areas) should receive more frequent sweeping;
  - Sweepers must be clean and maintained properly;
  - Operators must be trained to achieve the best performance

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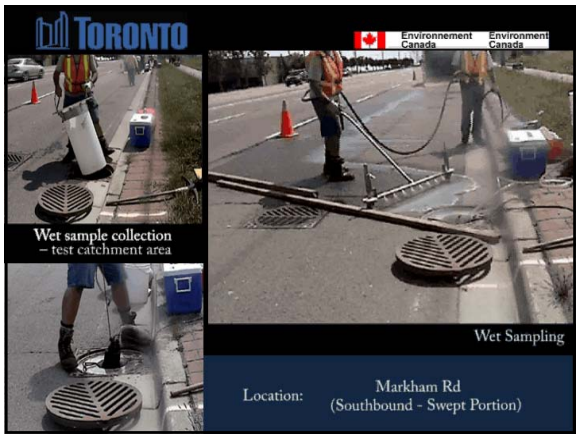
Stormwater Quality Evaluation



Recommendation

Recommend "dustless" regenerative-air street sweepers as a preferred technology at this time, meeting PM_{10} and $PM_{2.5}$ efficiency criteria, operational, performance and maintenance requirements

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2005 Street Sweeper RFP

First Stage

- Meet all mandatory requirements as specified in Section A and B of the Specifications
- Additional features as specified in Section C of the Specification were scored
- If mandatory requirements are met the Proponent will qualify for stage two of the process

Second Stage

- Mandatory testing and evaluation of regenerative-air street sweepers
  - the PM_{10} and $PM_{2.5}$ efficiency;
  - operational requirements; and
  - performance evaluation

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Results

- The City of Toronto has purchased 25 "dustless" regenerative-air street sweepers;
- In the near future Toronto will be purchasing additional sweepers in support of the City council's newly and unanimously endorsed combined air quality and climate change related policy;
- The evaluation process has provided a framework for the continuous development of new operational practices and procedures, ensuring that the City's street sweeping service is delivered in a safe, environmentally sustainable, efficient and effective manner; and
- This will be a standard by which we recommend and will use for all our future sweeper purchases.

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Benefits

Summary of Sweepings Hauled (tonnes)

Month	2006	2007
April	274.98	758.00
May	359.14	683.00
June	325.90	304.22
July	212.46	172.48
Total Sweepings Hauled	1172.48	1917.90

Ellesmere Yard is hauling 64% more street sweepings over the previous year

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Benefits

Regenerative-Air Street Sweepers
Remove 50% More PM from City Streets

14 TONNES OF PM

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Benefits

- Reduction of airborne particulate matter at street level, **by at least 21%;**
- Improvement in air quality will be beneficial to the **general health** of City's residents, workers and visitors;
- Reduces the number of cases of **acute** and **chronic exposure** of fine particulates;
- **Improves** stormwater quality and **reduces** the cost of stormwater treatment;
- Reduces maintenance costs
- **Reduces downtime** for unscheduled repairs
- Permits sweeping **during smog days** and will help to reduce smog impacts;
- Capable of street **sweeping year-around**; and
- Improve the level of **street sweeping service** across the City

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Municipal Requirement

Third Party Testing

- Developed a testing protocols and criteria to objectively evaluate the environmental and operational effectiveness of street sweepers now and in the future;
- ETV and PAMI were contracted by the City of Toronto to review the Protocol and witness the testing;
- A number of municipalities have indicated support in adopting the PM Efficiency Test and criteria as a new street sweeping municipal standard; and
- Tymco DST-6 regenerative-air street sweeper received and Environmental Technology Verification Certificate verifying the performance claims achieved using the City of Toronto Test Protocol.

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Enhancements to the CRCA Program

Best Practices

- Handling and cleaning of street sweepers - occupational health and safety review of procedures;
  - **Air quality inside cab;**
  - **Dust trap and dust filter cleaning procedures;**
- Waste stream management including:
  - **Storage of street sweeping debris in yards;**
  - **Manage sweepings entering catchbasins; and**
  - **Disposal and potential diversion of sweepings;**
- Monitoring changes of PM concentrations on swept City streets;
- On-going evaluation of the street sweeping frequency and street sweeper complement; and
- Incorporating PM efficient street sweepers in post construction sweeping contracts

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Enhancements to the CRCA Program

2008 Street Sweeper Monitoring

- To assess the effectiveness of City's new "regenerative-air" street sweepers in improving PM_{10} and $PM_{2.5}$ in Toronto;
  - **Ambient Air Quality Concentrations**
  - **Dust Disturbance by Sweepers**
- To evaluate the harmonized street sweeper level of service by **geography** and **road classification**;
- To **report back to Council** on
  - the effectiveness of new street sweepers;
  - resource requirements; and
  - impact to operating budget

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Clean Roads to Clean Air Program

Thank you for your interest and attention

Questions

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