WinSLAMM Modeling to Define Sediment Removal Rates for Street Sweeping Scenarios in the Chesapeake Bay Watershed

Source: San Mateo County, California

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1.0 INTRODUCTION

At its June 2013 meeting, the Chesapeake Bay Program's (CBP's) Urban Stormwater Work Group has approved the charge and membership of a street sweeping expert panel to assess and expand on an existing urban best management practice (BMP), "Street, Catch Basin and Storm Drain Cleaning." The panel was launched in September 2013. During its deliberations, the expert panel determined that it needed additional technical support to analyze the effect of different street sweeping options on pollutant removal for a wide range of street conditions in the Chesapeake Bay watershed. At its March 2014 meeting, the panel formulated the broad scope for the proposed modeling approach using WinSLAMM modeling. Tetra Tech is contracted by the CBP to perform this analysis as part its Total Maximum Daily Load (TMDL) Midpoint Assessment and Watershed Implementation Plan Support task.

The goal of this analysis is to perform technical analysis to support the current CBP Street Sweeping expert panel by evaluating the effectiveness of street sweeping. The expert panel has requested a series of model runs to determine the effectiveness of various sweeping management strategies using the existing street cleaning control device module in the most current version of WinSLAMM (Source Loading and Management Model for Windows) 10.1.0 (P&V Associates 2014; Pitt and Voorhees 2000).

This memorandum describes the results of the WinSLAMM analysis, which were used to develop the urban catchment representations, set up and test the model, and evaluate the baseline *no management* sediment loads from streets. The panel will review these results and the model setup will be revised as needed. The model will then be used to simulate the effects of different street cleaning scenarios.

2.0 WINSLAMM MODEL

2.1 Model Background

WinSLAMM was initially created to more efficiently evaluate stormwater BMPs. The program now includes a variety of source area and end-of-pipe controls. It was developed primarily as a planning level tool—generating information needed to make planning level decisions while not generating or requiring superfluous information—designed to give relatively simple answers (e.g., pollutant mass discharges and control measure effects for a variety of potential conditions).

WinSLAMM predicts the concentrations and loadings of many different pollutants from a large number of potential source areas. It calculates flow and pollutant discharges that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices.

WinSLAMM is an event-based model that calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls. It predicts the relative contributions of different source areas (e.g., roofs, streets, parking areas, landscaped areas, undeveloped areas) for each land use investigated. The particulate and pollutant loadings model results should be considered relative, not absolute, without calibrated data.

The model input parameters are:

- Rainfall
- Pollutant Data
- Land Use Data

Optional BMP inputs are considered as:

- Existing
- Proposed

Output results are:

- Runoff
- Pollutant Loadings

WinSLAMM uses the concept of small storm hydrology (Appendix A) to calculate runoff volumes and pollutant loadings for urban drainage basins for all rainfall events over a defined period.

WinSLAMM calculates the runoff volume for each rainfall event in a model run. First, the program determines the runoff coefficient (the ratio of runoff to rainfall as a function of rainfall depth) for each medium density residential source area, for each rainfall event. This coefficient is calculated from the runoff coefficient (Rv), or RSV file table the user has selected for the model run. The Rv values increase as the rain depth increases, reflecting the increasing yield of rainfall to runoff as the runoff losses become satisfied.

Each runoff coefficient is interpolated from the RSV file for each source area and rainfall depth. It is multiplied by the rainfall depth and appropriate source area to determine the runoff volume. Runoff volume coefficients do not vary by land use, but by surface cover at the source area and rain depth. The runoff volume equation is:

$$\text{Runoff Volume (ft}^3\text{)} = \text{Rainfall Depth (in)} \times \text{Source Area (acre)} \times \text{Rv} \times \text{Unit Conversion}$$

For total suspended solids calculations, WinSLAMM determines the particulate solids concentration for each source area in each land use, for each rainfall event. This coefficient is calculated from the particulate solids concentration from the selected PSC file table for the model run. Each particulate solids concentration is interpolated from the PSC file for each land use, source area, and rainfall depth. It is multiplied by the runoff volume to determine the particulate solids loading. The particulate solids loading equation is:

$$\text{Solids Loading (lbs)} = \text{Runoff Volume (ft}^3\text{)} \times \text{Solids Concentration (mg/L)} \times \text{Unit Conversion}$$

2.2 Model Development

2.2.1 Precipitation

The WinSLAMM model predicts urban stormwater runoff and pollutant loading in response to precipitation events. The frequency and magnitude of these events and the resulting responses vary by geographic location, but percent reductions are expected to be relatively insensitive to small variations in precipitation. The primary analysis focuses on the Washington, D.C. area; however, WinSLAMM model runs were also conducted with an alternative set of precipitation time series from the Norfolk, VA area. The current Chesapeake Bay Watershed Model (CBM) calibration period is from 1995 through 2005 (USEPA 2010). The model uses many different weather stations to drive the model hydrology. Two of these stations are the Washington National Airport Station (CBM land-river-segment number F51013_PL7_4941_0000) and Norfolk (Virginia Beach) Station (CBM land-river-segment number A51710_JB0_7661_0000). The rainfall data from the Washington National Airport and Norfolk stations obtained from the CBP are shown in Figures 2-1 and 2-2, respectively. They present the event-based rainfall data from January 1995 to December 2005, which encompasses the entire calibration period. The rainfall data was processed assuming the minimum number of hours between rains is 6 hours and the minimum rainfall event depth is 0.01 inch. The rainfall data from the CBM does include the snowfall events, and they are using a temperature index based sub-model to tell when a rainfall event is snow in the HSPF model at the Bay program. Snowmelt is not simulated in WinSLAMM and all precipitation is simulated as rainfall. Snow accumulation is not a large concern for the Washington, D.C. area, but may be a greater concern in the northern parts of the watershed.

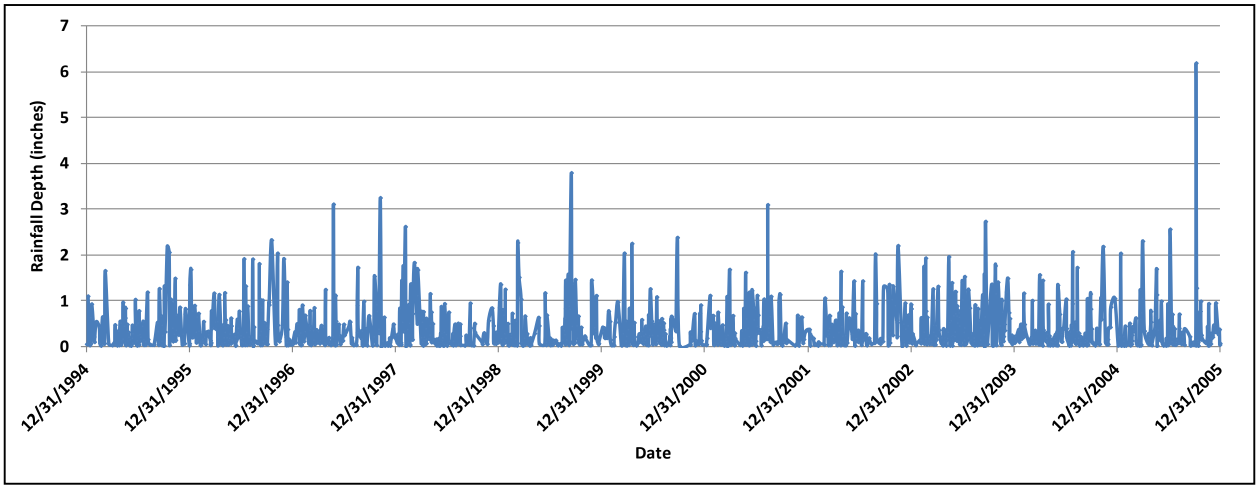

Figure 2-1. Rainfall data at Washington National Airport Station from 1995 to 2005.

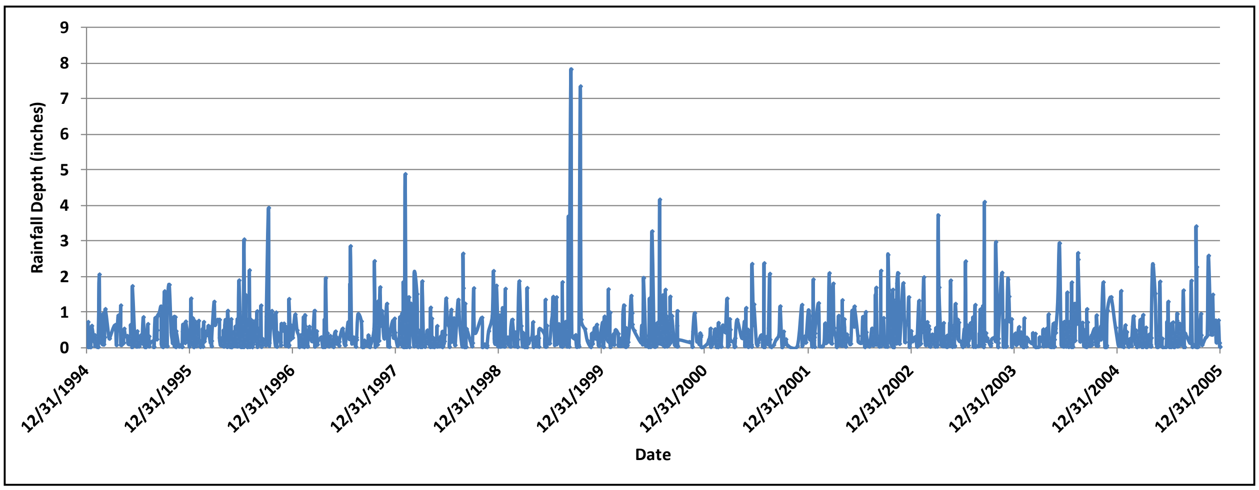

Figure 2-2. Rainfall data at Norfolk (Virginia Beach) Station from 1995 to 2005.

2.2.2 Default Input Files

WinSLAMM input files are summarized in Table 2-1. The input files were chosen from the East Coast April 2014 data in the National Stormwater Quality Database from the states shown in Figure 2-3 (Pitt et al. 2004). The East Coast file is representative of street conditions across the Chesapeake Bay watershed. The particle size distribution and peak-to-average flow ratio files were set to the program default average pavement and flow ratio files.

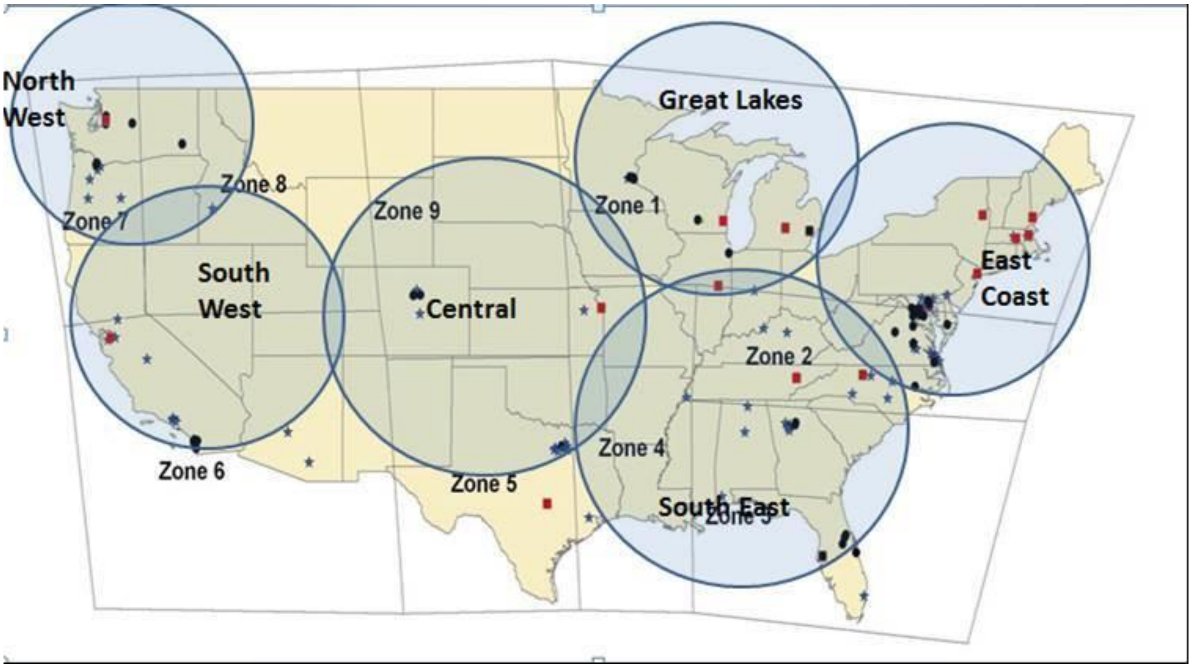

Figure 2-3. East Coast April 2014 data in the National Stormwater Quality Database (Pitt et al. 2004).

Table 2-1. Input files

File	Extension
Pollutant Probability Distribution File	.ppdx
Runoff Coefficient File	.rsvx
Particulate Solids Concentration File	.pscx
Particulate Residue Reduction File	.pprx
Street Delivery Parameter File	.std
Particle Size Distribution File	.cpz

2.2.3 Unit Urban Catchments

Tetra Tech simulated a set of four representative unit-area urban catchments that correspond to streets in different land use (residential, commercial, arterial [not limited access] highway, and ultra-urban). All streets were assumed to have a curb and gutter drainage system.

For conceptual purposes, we began by describing representative four-block areas that are assumed to contain a single land use plus streets (with curb and gutter drainage). For this task, the main interest is roads; therefore, in most unit areas only the roads are simulated in WinSLAMM. The general landscape concepts of the four designs are as follows and are summarized in Table 2-1.

1. **Single-family residential**: Approximately 0.25-acre lots, with cul-de-sacs connecting to two-lane residential feeder roads with parallel parking on one side; light traffic; and 25 mile-per-hour (mph) speed limit. Approximately 33 houses in a 10-acre area. The driveways are simulated as draining onto the roads.

2. **Commercial (80 percent impervious)**: Big box stores and parking lots. Feeder roads (two travel lanes and center turn lane) with no on-street parking, 35 mph speed limit, and heavy traffic.
3. **Ultra-urban downtown (95 percent impervious)**: Multistory buildings. Two-lane urban roads with parallel parking on both sides of the street, sidewalks, and 25 mph speed limit.
4. **Arterial highway in commercial area**: A four-lane divided road with median with barrier, high-speed traffic with turn lanes, and no on-street parking.

Table 2-2 presents the general conceptual plans of a 10-acre unit urban area with these characteristics. Bold red areas drain to the road and are directly relevant to the road condition. Bold green areas are road areas. The other land uses provide context that might be relevant for determining accumulation rates on the roads. We assume that roofs either drain to pervious areas or direct to storm drains, and not onto the roads. The only non-road land uses that drain onto the roads using the current assumptions are driveways, sidewalks, and the arterial road median. These are noted for information purposes only as WinSLAMM does not explicitly simulate road run-on effects.

Table 2-2. Landscape concepts of the four designs of a 10-acre unit urban area

Element	Single Family (acres)	Commercial (acres)	Ultra-Urban (acres)	Arterial (in ultra-urban area) (acres)
Roof	1.06	2.80	7.7	5.775
Driveway	**0.44**			
Urban Pervious	6.52	2.10	0.2	0.15
Sidewalk	**0.34**	**0.77**	**0.8**	0.60
Local Road	**1.64**	**0.96**	**1.3**	0.975
Parking Lot		3.37		
Arterial Road				**2.25**
Arterial Median				**0.25**
Total	**10.0**	**10.0**	**10.0**	**10.0**

Note: Bold red areas drain to the road and are thus relevant to the road condition. Bold green areas are road areas. Non-bold black areas do not drain to the roads, and therefore are not relevant to this modeling effort.

2.3 Representative 5-Year Period

For the analysis, the Work Group requested WinSLAMM to be run for a representative 5-year period in the CBM calibration period (1995–2005). Tetra Tech analyzed rainfall data from the National Airport and Norfolk Stations for every 5 years starting in 1995 and ending in 2005 (e.g., 1995–1999 and 1996–2000). The results of each 5-year period were compared to the entire 11-year calibration period (Tables 2-4 and 2-5). The 5-year period of 2000–2004 shows the smallest deviation (0.1 inch) from the average of the 1995–2005 period for both stations. Therefore, 2000–2004 was selected as the representative 5 years for the entire period.

Table 2-4. 5-year Washington National Airport Station rainfall statistics (inches)

Year	Jan (in)	Feb (in)	Mar (in)	Apr (in)	May (in)	Jun (in)	Jul (in)	Aug (in)	Sep (in)	Oct (in)	Nov (in)	Dec (in)	Total (in)	Absolute Deviation From 1995–2005 Average (in)
1995–2005	**3.4**	**2.7**	**4.0**	**3.3**	**4.2**	**4.1**	**4.1**	**3.5**	**4.4**	**3.6**	**3.3**	**2.8**	**43.4**	**Not applicable**
1995–1999	4.7	2.9	4.3	2.7	4.1	3.4	2.8	2.8	5.5	3.6	3.6	2.5	42.9	0.6
1996–2000	4.7	3.0	4.7	3.4	3.5	3.7	2.8	3.3	5.6	2.2	2.9	2.5	42.5	0.9
1997–2001	3.9	3.0	4.8	3.1	3.3	3.9	2.8	4.0	4.5	1.5	2.1	2.1	38.9	4.5
1998–2002	3.7	2.5	4.7	3.5	3.2	4.0	2.9	3.8	4.5	1.9	1.9	2.5	39.0	4.5
1999–2003	3.0	2.7	4.3	3.2	3.8	4.5	3.9	4.5	5.5	2.6	2.7	3.0	43.8	0.4
2000–2004	**2.1**	**2.7**	**3.6**	**3.6**	**4.1**	**5.0**	**5.2**	**4.4**	**4.2**	**2.4**	**3.2**	**3.1**	**43.5**	**0.1**
2001–2005	2.2	2.6	3.7	3.5	4.5	4.6	5.5	4.1	3.3	4.4	3.3	3.3	45.1	1.7

Table 2-5. 5-year Norfolk Station rainfall statistics (inches)

Year	Jan (in)	Feb (in)	Mar (in)	Apr (in)	May (in)	Jun (in)	Jul (in)	Aug (in)	Sep (in)	Oct (in)	Nov (in)	Dec (in)	Total (in)	Absolute Deviation From 1995–2005 Average (in)
1995–2005	**3.6**	**3.3**	**3.7**	**3.5**	**3.7**	**4.6**	**5.9**	**5.6**	**5.2**	**4.4**	**2.9**	**3.3**	**49.7**	**Not applicable**
1995–1999	4.2	4.2	3.5	3.4	3.0	3.6	5.8	4.0	6.0	5.2	2.9	3.3	49.2	0.6
1996–2000	4.7	3.8	3.8	3.8	3.3	4.1	7.0	5.6	6.1	4.2	2.6	3.2	52.2	2.5
1997–2001	3.9	3.6	3.8	3.4	3.1	4.2	5.7	5.5	5.8	3.3	1.9	2.8	47.1	2.6
1998–2002	4.6	3.3	4.6	3.2	3.6	4.6	5.0	6.2	6.2	3.6	2.1	3.2	50.1	0.4
1999–2003	3.9	2.5	4.4	3.8	3.8	4.6	5.6	6.0	7.6	3.9	2.3	3.1	51.7	2.0
2000–2004	3.2	2.5	4.0	3.6	4.1	5.4	6.2	7.0	4.8	2.9	2.8	3.2	49.8	0.1
2001–2005	2.8	2.8	4.0	3.4	4.3	5.2	5.6	6.5	4.3	4.4	3.2	3.7	50.1	0.4

3.0 BASELINE MODEL RESULTS

The WinSLAMM model was run for four land use combinations of scenarios for the representative 5-year period of 2000–2004 to establish the baseline no management sediment load discharged. The scenarios entailed four unit street loadings as detailed in Table 2-2.

The model uses the runoff coefficient (Rv) that is based on the type of land use area (flat or pitched roof, pervious or impervious, and soil type) from the runoff coefficient input files for the east coast. The program multiplies the source area times the runoff coefficient for each rainfall event times a conversion factor to determine the runoff volume for each source area and rainfall event. Details are provided in Appendix A.

Total Particulate Solids Load

The program uses the particulate solids concentration input file for each source area within each land use in the model. The program multiplies the runoff volume of each source area within each land use times the particulate solids concentration (PSC) for each rainfall event times a conversion factor to determine the total particulate solids loading for each source area and rainfall event.

The particulate solids concentration values for different land uses are calibrated from monitored data from the Birmingham, Alabama area in WinSLAMM.

Street Load Calculation

The street load calculation is a separate calculation from particulate solids load, which gives the total sediment yield. The street load calculation does not use the runoff volume and PSCs. It calculates the street dirt load accumulation starting with an initial approximate load and use empirical accumulation rate to calculate street accumulated load over the modeling period and deducts the washed off dirt load . The street load calculation only uses rain intensity and duration (for rain volume) in the washoff calculation.

Street Dirt Accumulation

Street dirt accumulation is expressed in WinSLAMM as a function of the initial load, initial deposition rate, time (after a rain event or street cleaning event), and a fugitive dust loss fraction. The initial street dirt load is the default value by the program using the defined street texture and land use. The model uses an initial intermediate roughness and street width and length and to calculate the accumulation rate. After a rainfall or street cleaning event, the street dirt loading equation uses a higher initial street dirt loading rate on the basis of the previous events. The rate of material accumulation on the street decreases over time, until the maximum street dirt loading is reached.

WinSLAMM calculates the street dirt load in lbs/curb-miles using the dirt deposition rate and number of deposition days, and smoothness of the street. Complete detail is provided in Appendix B. The model uses the following equation to calculate the street dirt load at the end of any given time period:

$$SDLoad_i = SDLoad_{i-1} + SDDepRate \times AccRateReducFrac_{(i-1)} \times (PerNum-1) \times NumDays$$

where:

- $SDLoad_i$ = Street dirt load at the end of a given time period (lbs/curb-mi)
- $SDLoad_{i-1}$ = Street dirt load at the end of the previous time period (lbs/curb-mi)

- i = The time period number that a given street dirt accumulation rate is applied
- SDDepRate = Street dirt deposition rate (lbs/curb-mi/day), the variable 'm' in the street source area parameter entry window in WinSLAMM
- AccRateReducFrac = The fraction that the deposition rate is reduced by, for each time period, due to fugitive dust losses. This value is fixed in the program.
- PerNum = The time period number
- NumDays = The number of days per time period

The program divides the accumulation curve into even periods to determine the street dirt loading at a given time after the end of a washoff or street cleaning event. The accumulation rate is progressively reduced for each period by the accumulation rate reduction fraction. This fraction is multiplied by the accumulation rate for each period. The street dirt load from this period is added to the load from the previous period.

The accumulation rate reduction fractions and street base load only change with street texture. Because we are assuming smooth street texture in all our four land uses, these values will remain constant at 0.75 for the accumulation rate reduction fraction and 225 lbs/yr/curb-mile for the street base load. The accumulation rate reduction period is 5 days for ccommercial areas and 15 days for residential, arterial, and ultra-urban areas. This will cause the difference in average street dirt load (lbs/yr/curb-mile) between commercial and the rest of land uses.

Washoff

- The equation for washoff is the following. $dN/dt = k \times r \times N$

where:

- dN/dt = Change in street dirt loading per unit time
- k = Proportionality constant
- r = Rain intensity (in/h)
- N = Street dirt loading (lb/curb-mile)

Upon integration, this equation becomes:

$$N = N_o \times e^{(-krt)}$$

where:

- N = Residual street dirt load (after the rain)
- N_o = Initial street dirt load
- t = Rain duration

Street dirt washoff is therefore equal to N_o-N. The variable combination *rt* (rain intensity times rain duration) is equal to total rain volume (R). This equation further reduces to:

$$N = N_o \times e^{(-kR)}$$

Therefore, this equation is sensitive to total rain. Because of decreasing particulate supplies, the exponential washoff curve predicts decreasing concentrations of particulates with time since the start of a rain.

Sartor and Boyd (1972) found the proportionality constant (k) to be slightly dependent on street texture and condition, but independent of rain intensity and particle size. The initial street dirt load (N_o) is only the portion of the total street load available for washoff. WinSLAMM uses an availability factor for total solids on the street using extensive field monitoring observations to reduce the washoff quantity to what is available for washoff. WinSLAMM also uses a street delivery fraction as an additional calibration tool to adjust the initial calculated washoff fraction to determine the final washoff load.

Table 3-1 shows the differences in runoff volume, runoff coefficient, annual particulate solids load and average street dirt load for the four different land uses, respectively, using the Washington National Airport and Norfolk rainfall station data.

Table 3-1. Baseline model results

Land Use	Washington National Airport Weather				Norfolk Weather			
	Runoff Volume (cf/yr)	Runoff Coefficient (Rv)	Particulate Solids Yield per Year (lbs/yr)	Average Street Dirt Load (lb/yr/cu-mi)	Runoff Volume (cf/yr)	Runoff Coefficient (Rv)	Particulate Solids Yield per Year (lbs/yr)	Average Street Dirt Load (lb/yr/cu-mi)
Arterial	568,912	0.36	14,245	375	696,394	0.39	15,468	386
Commercial	279,731	0.18	3,417	313	363,187	0.20	3,903	317
Residential	363,774	0.23	3,048	375	460,126	0.25	3,795	386
Ultra-Urban	324,368	0.21	5,883	375	414,715	0.23	6,521	386

Notes: cf/yr = cubic feet per year; lbs/yr = pounds per year; lb/yr/cu-mi = pounds per year per curb mile.

The total recorded rainfall at the Norfolk station is greater than the National Airport station. The annual runoff volume using the National Airport rainfall is the highest for the arterial land use (568,912 cubic feet per year) and the lowest for commercial land use (279,731 cubic feet per year). The annual particulate solids yield is the lowest (3,048 pounds per year) for residential land use and the highest (14,245 pounds per year) for arterial land use.

Using the Norfolk (Virginia Beach) rainfall station, the annual runoff is again highest (696,394 cubic feet per year) for arterial and the lowest (363,187 cubic feet per year) for commercial land use as shown in Table 3-1. The annual particulate solids yield is the lowest (3,795 pounds per year) for residential land use and the highest (15,468 pounds per year) for arterial land use. There is more rainfall in Norfolk station than National Airport station; therefore, the runoff and particulate solid yield are greater.

4.0 STREET SWEEPING SCENARIOS

Sediment loads from streets are a function of model parameters such as the street dirt wash-off rate, solids accumulation rates, and productivity functions for street cleaning. A series of sweeping scenario runs were developed under three different winter season street sweeping ranges (e.g., start/stop time for the sweeping period) are specified as follows:

- Sweeping the entire year
- Suspend sweeping December 1/Restart March 15
- Suspend sweeping December 15/ Restart February 15

The effect of street cleaning were run for the four land use baseline street conditions for a range of scenarios involving sweeping technology, frequency, parking density, and parking restrictions to facilitate sweeping (which is only relevant on streets where parking is allowed). Table 4-1 presents the scenarios assessed in the street cleaning control device module. The seasonal scenarios were split to two or three runs where the sweeping dates exceeded the maximum WinSLAMM input line amount, thus preventing WinSLAMM from running. The results were then added to calculate the total load and sedimentation removal rate.

Table 4-1. Sweeping scenarios technology, frequency, parking density and control

Frequency	Technology	Parking Density	Parking Restriction Imposed
Two Passes Per Week	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
One Pass Per Week	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
One Pass Every Two Weeks	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
One Pass Every Four Weeks	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No

Frequency	Technology	Parking Density	Parking Restriction Imposed
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
One Pass Every Eight Weeks	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
One Pass Every Twelve Weeks	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
Seasonal 1: • Spring – One Pass Every Week from March to April • Monthly Otherwise	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
Seasonal 2: • Spring – One Pass Every Other Week from March to April • Monthly otherwise	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
Seasonal 3: • Spring and Fall – One Pass Every Week (March to April, October to November) • Monthly Otherwise	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable
		Extensive	Yes
			No
Seasonal 4: • Spring and Fall – One Pass Every Other Week During the Season • Monthly Otherwise	Mechanical Broom Cleaner	None	Not Applicable
		Extensive	Yes
			No
	Vacuum Assisted/Vacuum or Regenerative Air Cleaner	None	Not Applicable

Frequency	Technology	Parking Density	Parking Restriction Imposed
		Extensive	Yes
			No

It is important to note some limitations of the scenarios regarding parking. This investigation only evaluated the end members of no parking and extensive or high-density parking. Based on Bob Pitt's research (Appendix B), in a high-density parking condition, parking spaces are saturated, which implies that all available curb-side spaces have a high probability of being occupied by parked cars. As a result, most street dirt accumulates in the driving lanes. The vehicle turbulence from passing cars blows the street dirt towards the curb, however, parked cars block the sediment, so the sediment settles on the street side of the car. If no cars were present, the blown dirt would be obstructed by the curb itself and settle at the edges of the street where street sweeping is usually conducted. Removing the cars to clean next to the curbs misses much of the street dirt that resides further from the curb. Different street sweeping strategies or equipment might better address this issue, but were not investigated here. Further, removal efficiency (with or without parking controls) is expected to be greater under conditions of moderate parking density, under which dirt is more likely to be blown to the curbs. Additional analyses could be performed to address other parking densities. Refer to Appendix B for further discussion of these issues.

5.0 MODEL RESULTS

Cleaning scenarios results for residential, commercial, arterial, and ultra-urban land use are summarized respectively in Tables 5-1 to 5-3, 5-4 to 5-6, 5-7 to 5-9, and 5-10 to 5-12. The final result of the model is the particulate solids yield percent reduction (PSYR) presented in percentage.

The tables use the following acronyms:

- Frequency:
  - 2PW = 2 passes per week;
  - 1PW = 1 pass every week;
  - 1P2W = 1 pass every 2 weeks (frequency in the current CBP-approved street sweeping BMP);
  - 1P4W = 1 pass every 4 weeks;
  - 1P8W = 1 pass every 8 weeks;
  - 1P12W = 1 pass every 12 weeks
  - S1 = Spring – One pass every week from March to April. Monthly otherwise
  - S2 = Spring – One pass every other week from March to April. Monthly otherwise
  - S3 = Spring and fall – One pass every week (March to April, October to November). Monthly otherwise
  - S4 = Spring and fall – One pass every other week during the season. Monthly otherwise

  Technology:
  - MBC = Mechanical broom cleaning
  - VAC = Vacuum assisted cleaning
  - Ext = Extensive (long-term) parking density
  - Non = No parking density
  - Yes = Parking restriction (e.g. parking signs and meters) imposed
  - No = Parking restriction not imposed
- RPSLY = Reduced particulate solids yield (lbs/yr)
- PSYPR = Particulate solids yield percent reduction

The solids load removed as a function of the total number of sweeping passes in a year for each scenario is shown in Figures 5-1 to 5-10 for different winter stop periods, parking restrictions, and cleaning technologies. This information can be used to infer benefit per operational cost of sweeping. Total removal increases with additional sweeping passes, but the relationship is non-linear with decreasing returns as frequency increases. Some of the seasonal scenarios achieve somewhat greater rates of removal per number of sweeping passes than the non-seasonal scenarios.

These results are the total removal rates at the outfall, which include sources other than streets (e.g., rooftops, driveways, walkways) and can be the reason for low average street cleaning reduction values compared to a solely street reduction analysis.

Table 5-1. Results for residential land use with sweeping the entire year

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	81	1.0
×											×	×			×	1,021	12.9
×											×	×		×		2,181	27.7
×											×		×		×	2,999	38.0
	×									×		×			×	0	0.0
	×									×		×		×		1	0.0
	×									×			×		×	56	0.7
	×										×	×			×	662	8.4
	×										×	×		×		1,577	20.0
	×										×		×		×	2,350	29.8
		×								×		×			×	0	0.0
		×								×		×		×		0	0.0
		×								×			×		×	28	0.4
		×									×	×			×	362	4.6
		×									×	×		×		944	12.0
		×									×		×		×	1,533	19.4
			×							×		×			×	0	0.0
			×							×		×		×		0	0.0
			×							×			×		×	18	0.2
			×								×	×			×	180	2.3
			×								×	×		×		492	6.2
			×								×		×		×	826	10.5
				×						×		×			×	0	0.0
				×						×		×		×		0	0.0
				×						×			×		×	5	0.1
				×							×	×			×	112	1.4
				×							×	×		×		289	3.7
				×							×		×		×	490	6.2
					×					×		×			×	0	0.0
					×					×		×		×		0	0.0
					×					×			×		×	0	0.0
					×						×	×			×	72	0.9
					×						×	×		×		189	2.4
					×						×		×		×	324	4.1
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	28	0.4
						×					×	×			×	264	3.4
						×					×	×		×		672	8.5
						×					×		×		×	1,090	13.8
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	27	0.3
							×				×	×			×	223	2.8

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×		×		583	7.4
							×				×		×		×	977	12.4
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	97	1.2
								×			×	×			×	471	5.9
								×			×	×		×		1,065	13.4
								×			×		×		×	1,618	20.4
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	80	1.0
									×		×	×			×	415	5.2
									×		×	×		×		969	12.2
									×		×		×		×	1,499	18.9

Table 5-2. Results for residential land use for scenario to suspend sweeping December 15/Restart February 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	69	0.9
×											×	×			×	861	10.9
×											×	×		×		1,878	23.8
×											×		×		×	2,623	33.3
	×									×		×			×	0	0.0
	×									×		×		×		1	0.0
	×									×			×		×	60	0.8
	×										×	×			×	549	7.0
	×										×	×		×		1,364	17.3
	×										×		×		×	2,056	26.1
		×								×		×			×	0	0.0
		×								×		×		×		1	0.0
		×								×			×		×	52	0.7
		×									×	×			×	337	4.3
		×									×	×		×		873	11.1
		×									×		×		×	1,418	18.0
			×							×		×			×	0	0.0
			×							×		×		×		1	0.0
			×							×			×		×	19	0.3
			×								×	×			×	192	2.4
			×								×	×		×		511	6.5
			×								×		×		×	871	11.1
				×						×		×			×	0	0.0
				×						×		×		×		1	0.0
				×						×			×		×	16	0.2
				×							×	×			×	95	1.2
				×							×	×		×		258	3.3
				×							×		×		×	445	5.7
					×					×		×			×	0	0.0
					×					×		×		×		0	0.0
					×					×			×		×	4	0.1
					×						×	×			×	98	1.3
					×						×	×		×		240	3.0
					×						×		×		×	399	5.1
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	30	0.4
						×					×	×			×	285	3.6
						×					×	×		×		705	8.9
						×					×		×		×	1,118	14.0
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	27	0.3

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×			×	231	2.9
							×				×	×		×		594	7.5
							×				×		×		×	986	12.4
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	54	0.7
								×			×	×			×	465	5.8
								×			×	×		×		1,077	13.5
								×			×		×		×	1,620	20.3
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	34	0.4
									×		×	×			×	297	3.7
									×		×	×		×		752	9.4
									×		×		×		×	1,223	15.3

Table 5-3. Results for residential land use for scenario to suspend sweeping December 1/Restart March 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	50	0.6
×											×	×			×	687	8.7
×											×	×		×		1,576	20.0
×											×		×		×	2,246	28.5
	×									×		×			×	0	0.0
	×									×		×		×		1	0.0
	×									×			×		×	42	0.5
	×										×	×			×	447	5.7
	×										×	×		×		1,154	14.6
	×										×		×		×	1,775	22.5
		×								×		×			×	0	0.0
		×								×		×		×		1	0.0
		×								×			×		×	37	0.5
		×									×	×			×	267	3.4
		×									×	×		×		730	9.3
		×									×		×		×	1,207	15.3
			×							×		×			×	0	0.0
			×							×		×		×		1	0.0
			×							×			×		×	20	0.3
			×								×	×			×	173	2.2
			×								×	×		×		465	5.9
			×								×		×		×	798	10.1
				×						×		×			×	0	0.0
				×						×		×		×		0	0.0
				×						×			×		×	4	0.1
				×							×	×			×	108	1.4
				×							×	×		×		286	3.6
				×							×		×		×	494	6.3
					×					×		×			×	0	0.0
					×					×		×		×		1	0.0
					×					×			×		×	16	0.2
					×						×	×			×	75	1.0
					×						×	×		×		206	2.6
					×						×		×		×	356	4.5
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	14	0.2
						×					×	×			×	187	2.4
						×					×	×		×		504	6.3
						×					×		×		×	838	10.5
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	14	0.2

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×			×	160	2.0
							×				×	×		×		439	5.5
							×				×		×		×	757	9.5
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	35	0.4
								×			×	×			×	343	4.3
								×			×	×		×		828	10.4
								×			×		×		×	1,288	16.1
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	17	0.2
									×		×	×			×	216	2.7
									×		×	×		×		577	7.2
									×		×		×		×	969	12.1

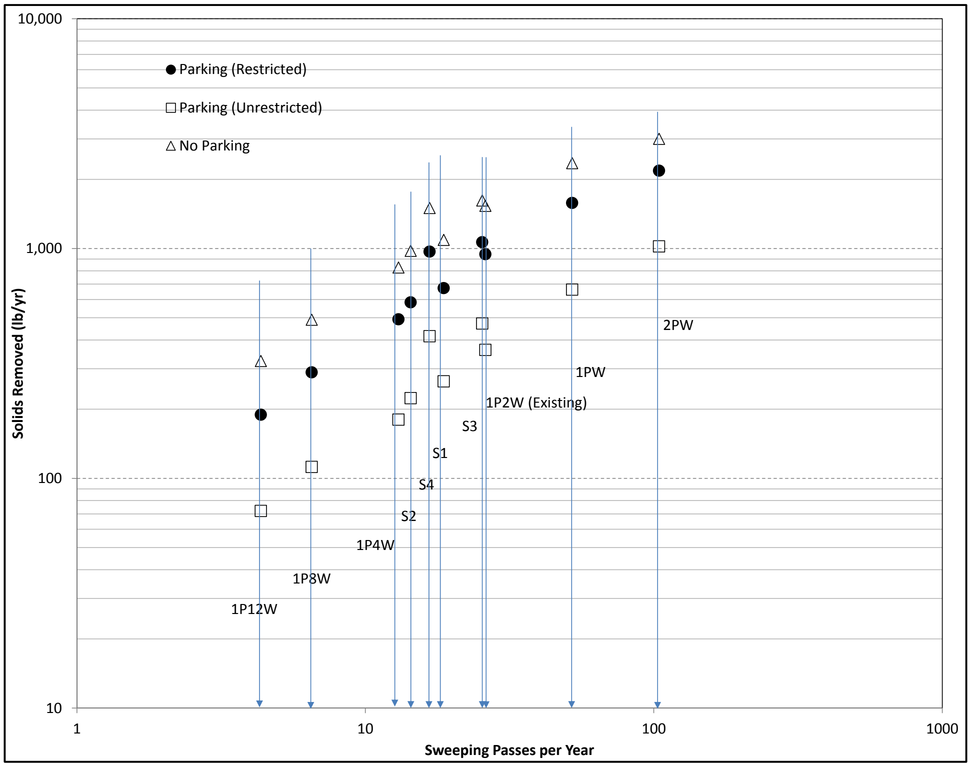

Figure 5-1. Residential solid removal rates for different sweeping frequencies and parking restrictions.

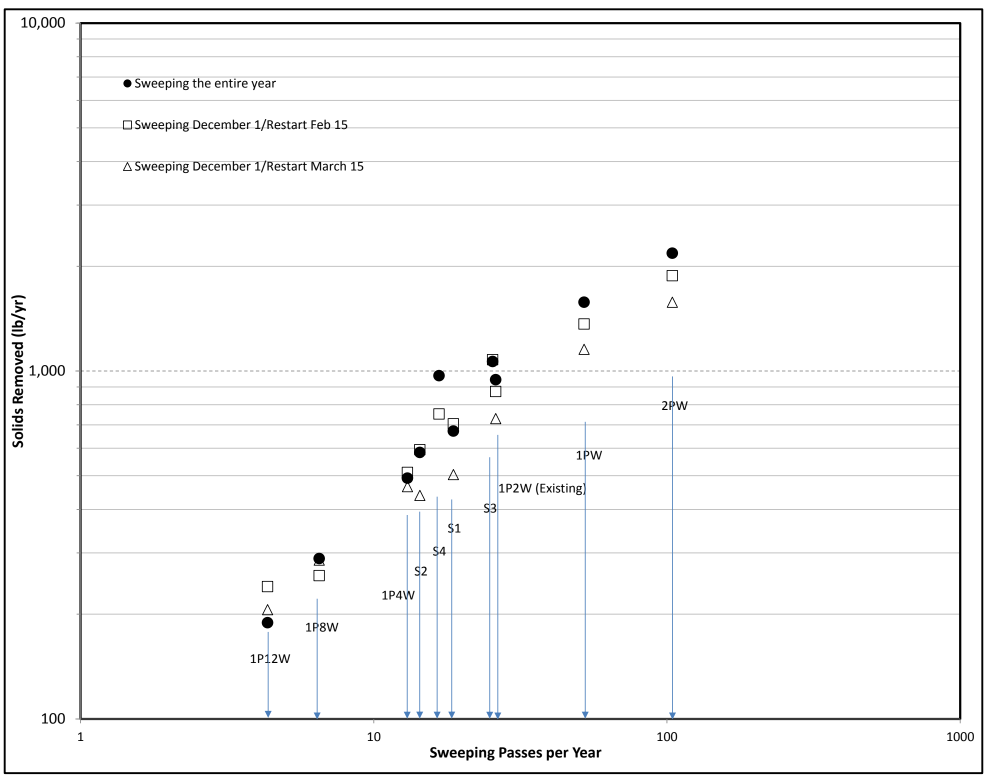

Figure 5-2. Residential solid removal rates for different sweeping frequencies and winter stops.

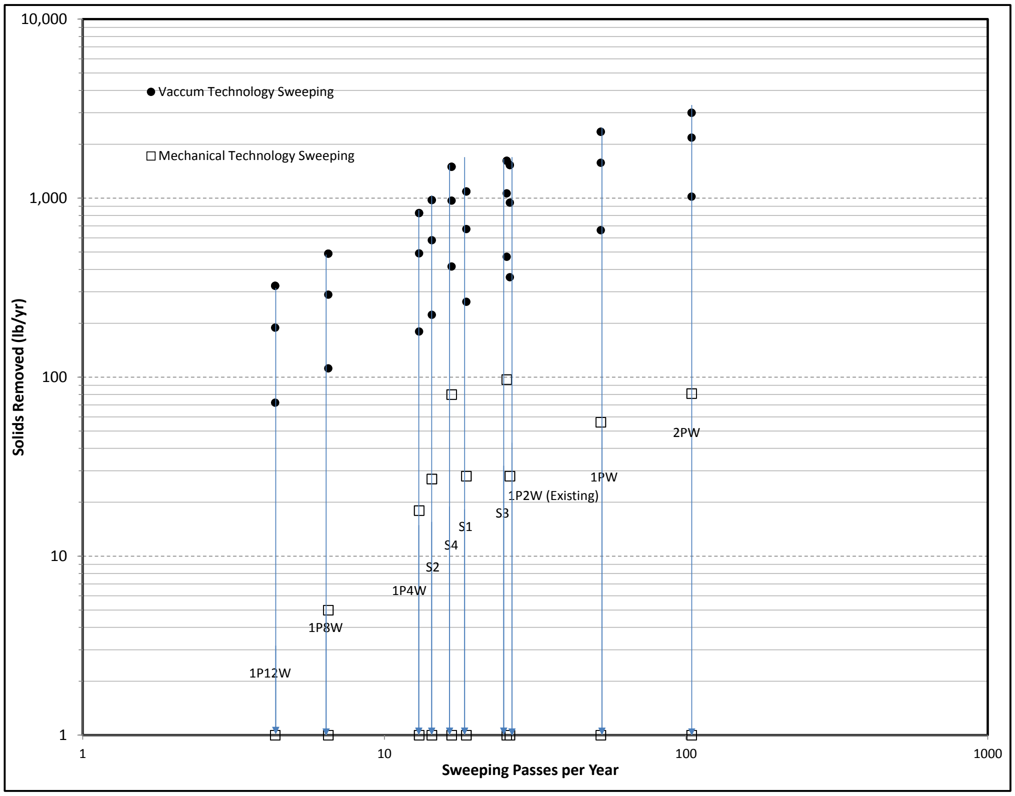

Figure 5-3. Residential solid removal rates for different sweeping frequencies and technologies.

Table 5-4. Results for commercial land use for sweeping the entire year

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	30	0.1
×											×		×		×	2,802	10.9
	×									×			×		×	16	0.1
	×										×		×		×	1,921	8.6
		×								×			×		×	12	0.1
		×									×		×		×	1,134	5.0
			×							×			×		×	8	0.0
			×								×		×		×	579	2.6
				×						×			×		×	8	0.0
				×							×		×		×	331	1.5
					×					×			×		×	8	0.0
					×						×		×		×	227	1.0
						×				×			×		×	16	0.2
						×					×		×		×	638	8.4
							×			×			×		×	16	0.2
							×				×		×		×	572	7.6
								×		×			×		×	57	0.7
								×			×		×		×	947	12.5
									×	×			×		×	34	0.4
									×		×		×		×	740	9.7

Note: The commercial land use scenario assumes on-street parking is not allowed.

Table 5-5. Results for commercial land use for scenario to suspend sweeping December 15/Restart February 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	40	0.5
×											×		×		×	1,535	20.3
	×									×			×		×	35	0.5
	×										×		×		×	1,204	15.9
		×								×			×		×	30	0.4
		×									×		×		×	830	11.0
			×							×			×		×	11	0.2
			×								×		×		×	510	6.7
				×						×			×		×	9	0.1
				×							×		×		×	261	3.4
					×					×			×		×	2	0.0
					×						×		×		×	233	3.1
						×				×			×		×	18	0.2
						×					×		×		×	654	8.6
							×			×			×		×	16	0.2
							×				×		×		×	577	7.6
								×		×			×		×	31	0.4
								×			×		×		×	948	12.4
									×	×			×		×	29	0.4
									×		×		×		×	1,033	13.1

Note: The commercial land use scenario assumes on-street parking is not allowed.

Table 5-6. Results for commercial land use for scenario to suspend sweeping December 1/Restart March 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	4	0.0
×											×		×		×	2,018	9.0
	×									×			×		×	4	0.0
	×										×		×		×	1,439	6.4
		×								×			×		×	3	0.0
		×									×		×		×	885	3.9
			×							×			×		×	0	0.0
			×								×		×		×	532	2.4
				×						×			×		×	0	0.0
				×							×		×		×	309	1.4
					×					×			×		×	0	0.0
					×						×		×		×	228	1.0
						×				×			×		×	8	0.1
						×					×		×		×	490	6.4
							×			×			×		×	8	0.1
							×				×		×		×	443	5.8
								×		×			×		×	20	0.3
								×			×		×		×	754	9.9
									×	×			×		×	10	0.1
									×		×		×		×	567	7.4

Note: The commercial land use scenario assumes on-street parking is not allowed.

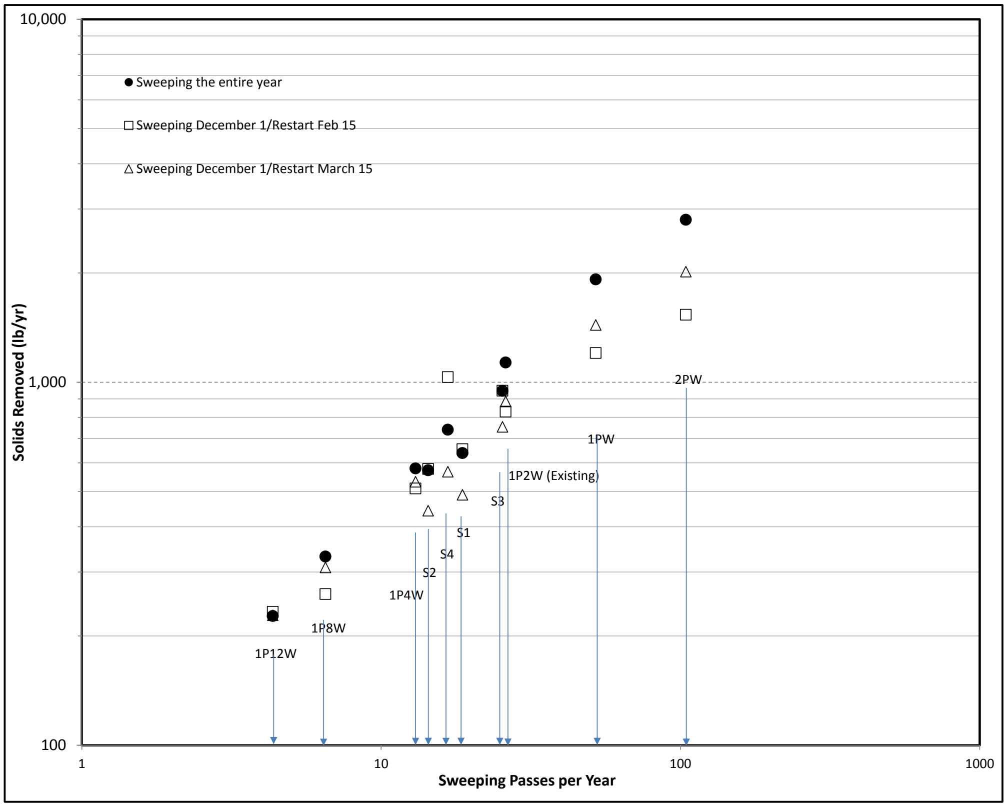

Figure 5-4. Commercial solid removal rates for different sweeping frequencies and winter stops.

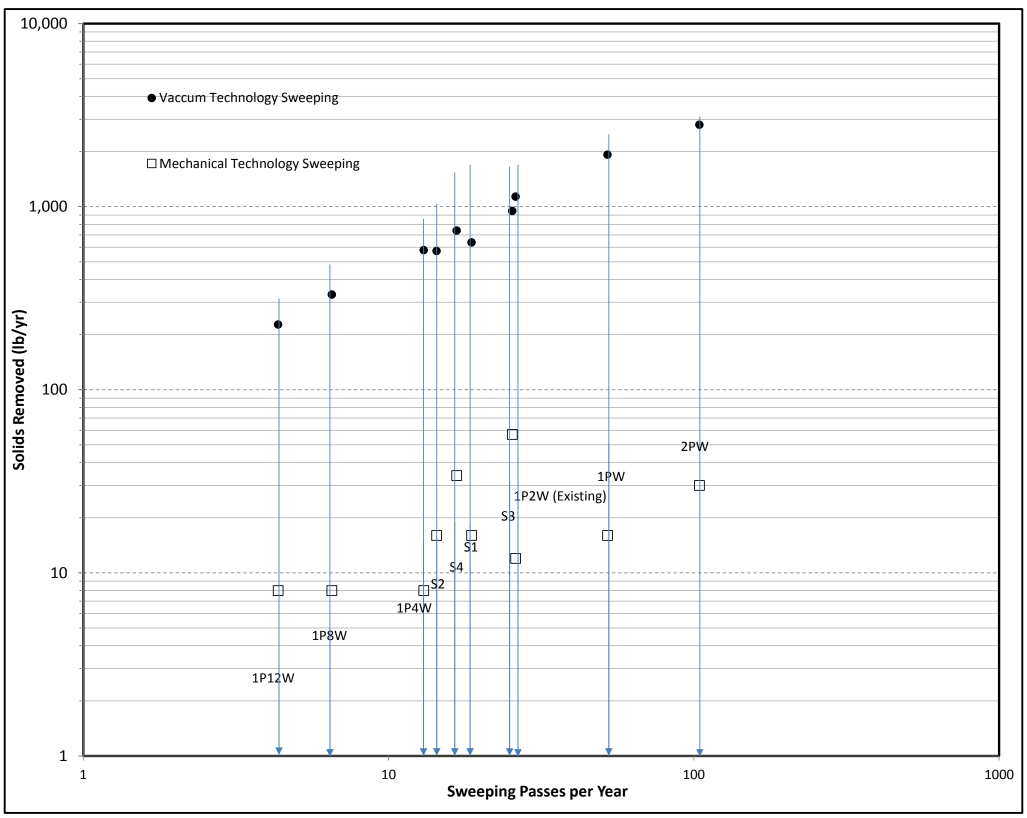

Figure 5-5. Commercial solid removal rates for different sweeping frequencies and technologies.

Table 5-7. Results for arterial land use with sweeping the entire year

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	172	1.2
×											×		×		×	6,354	44.6
	×									×			×		×	119	0.8
	×										×		×		×	4,979	35.0
		×								×			×		×	58	0.4
		×									×		×		×	3,247	22.8
			×							×			×		×	37	0.3
			×								×		×		×	1,749	12.3
				×						×			×		×	11	0.1
				×							×		×		×	1,038	7.3
					×					×			×		×	0	0.0
					×						×		×		×	687	4.8
						×				×			×		×	59	0.4
						×					×		×		×	2,310	16.2
							×			×			×		×	56	0.4
							×				×		×		×	2,070	14.5
								×		×			×		×	206	1.4
								×			×		×		×	3,429	23.8
									×	×			×		×	123	0.9
									×		×		×		×	2,679	18.6

Note: The arterial land use scenario assumes on-street parking is not allowed.

Table 5-8. Results for arterial land use for scenario to suspend sweeping December 15/Restart February 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	145	1.0
×											×		×		×	5,559	39.0
	×									×			×		×	128	0.9
	×										×		×		×	4,357	29.7
		×								×			×		×	110	0.8
		×									×		×		×	3,005	21.1
			×							×			×		×	17	0.3
			×								×		×		×	770	12.3
				×						×			×		×	34	0.2
				×							×		×		×	944	5.7
					×					×			×		×	8	0.1
					×						×		×		×	845	5.9
						×				×			×		×	64	0.4
						×					×		×		×	2,368	16.4
							×			×			×		×	57	0.4
							×				×		×		×	2,089	14.5
								×		×			×		×	114	0.8
								×			×		×		×	3,433	23.8
									×	×			×		×	72	0.5
									×		×		×		×	2,628	18.2

Note: The arterial land use scenario assumes on-street parking is not allowed.

Table 5-9. Results for arterial land use for scenario to suspend sweeping December 1/Restart March 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×			×		×	105	0.7
×											×		×		×	4,759	33.4
	×									×			×		×	128	0.9
	×										×		×		×	4,357	30.6
		×								×			×		×	79	0.6
		×									×		×		×	2,557	18.0
			×							×			×		×	42	0.3
			×								×		×		×	1,691	11.9
				×						×			×		×	9	0.1
				×							×		×		×	1,048	7.4
					×					×			×		×	33	0.2
					×						×		×		×	753	5.3
						×				×			×		×	30	0.2
						×					×		×		×	1,775	11.5
							×			×			×		×	30	0.2
							×				×		×		×	1,604	10.3
								×		×			×		×	73	0.5
								×			×		×		×	2,728	17.9
									×	×			×		×	78	0.5
									×		×		×		×	2,268	14.2

Note: The arterial land use scenario assumes on-street parking is not allowed.

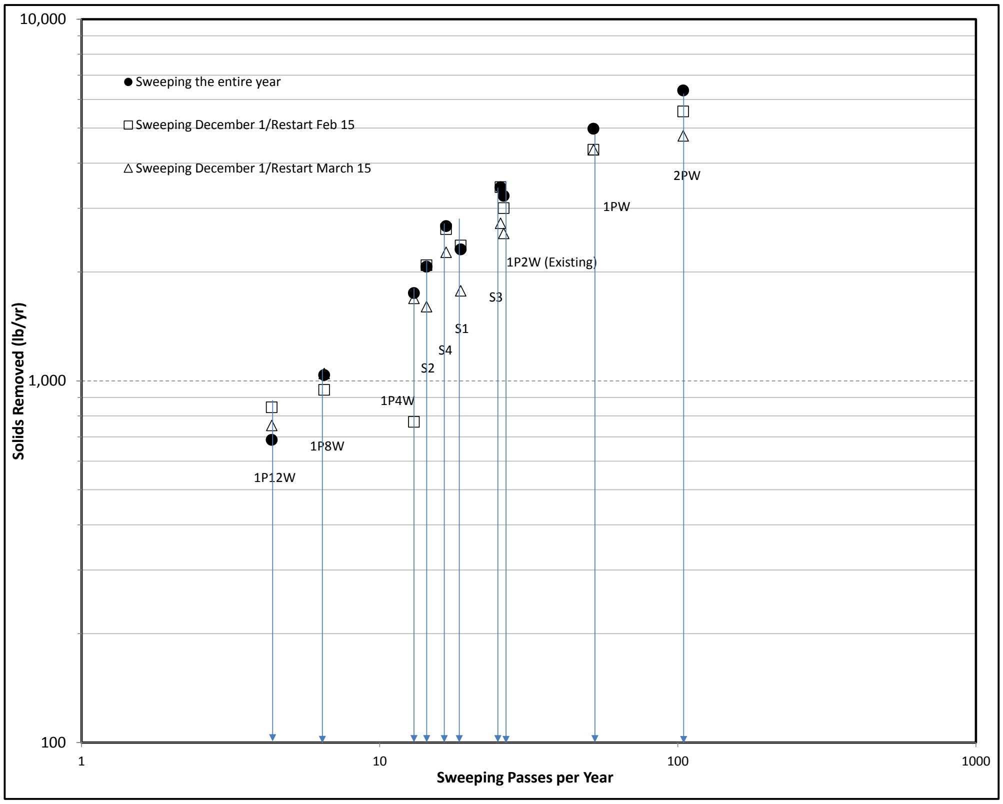

Figure 5-6. Arterial solid removal rates for different sweeping frequencies and winter stops.

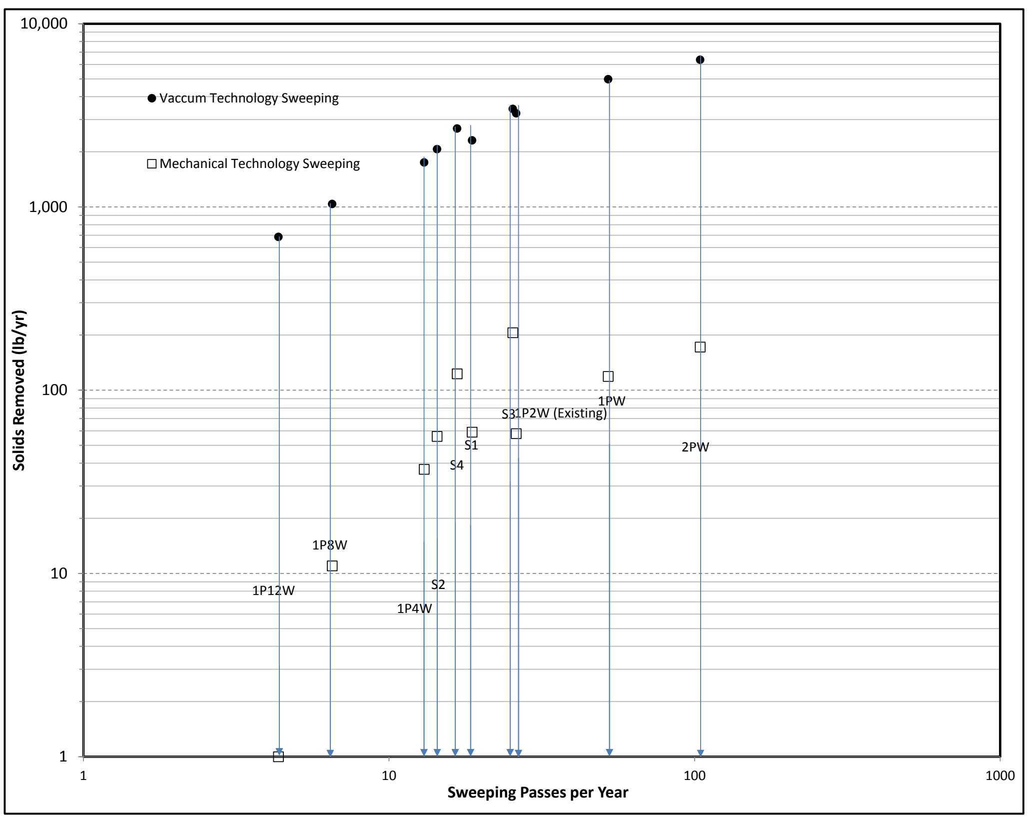

Figure 5-7. Arterial solid removal rates for different sweeping frequencies and technologies.

Table 5-10. Results for ultra-urban land use with sweeping the entire year

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	40	1.0
×											×	×			×	498	12.7
×											×	×		×		1,064	27.2
×											×		×		×	1,463	37.3
	×									×		×			×	0	0.0
	×									×		×		×		0	0.0
	×									×			×		×	45	0.8
	×										×	×			×	525	8.9
	×										×	×		×		1,250	21.2
	×										×		×		×	1,862	31.7
		×								×		×			×	0	0.0
		×								×		×		×		0	0.0
		×								×			×		×	22	0.4
		×									×	×			×	287	4.9
		×									×	×		×		748	12.7
		×									×		×		×	1,215	20.7
			×							×		×			×	0	0.0
			×							×		×		×		0	0.0
			×							×			×		×	14	0.2
			×								×	×			×	143	2.4
			×								×	×		×		390	6.6
			×								×		×		×	654	11.1
				×						×		×			×	0	0.0
				×						×		×		×		0	0.0
				×						×			×		×	4	0.1
				×							×	×			×	89	1.5
				×							×	×		×		229	3.9
				×							×		×		×	388	6.6
					×					×		×			×	0	0.0
					×					×		×		×		0	0.0
					×					×			×		×	0	0.0
					×						×	×			×	57	1.0
					×						×	×		×		150	2.6
					×						×		×		×	257	4.5
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	22	0.4
						×					×	×			×	222	3.9
						×					×	×		×		551	9.7
						×					×		×		×	886	15.5
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	21	0.4
							×				×	×			×	177	3.0

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×		×		462	7.9
							×				×		×		×	774	13.2
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	77	1.3
								×			×	×			×	373	6.3
								×			×	×		×		844	14.2
								×			×		×		×	1,283	21.6
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	46	0.8
									×		×	×			×	254	4.3
									×		×	×		×		617	10.4
									×		×		×		×	1,002	16.9

Table 5-11. Results for ultra-urban land use for scenario to suspend sweeping December 15/Restart February 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	54	1.0
×											×	×			×	680	11.9
×											×	×		×		1,484	26.1
×											×		×		×	2,074	36.4
	×									×		×			×	0	0.0
	×									×		×		×		1	0.0
	×									×			×		×	48	0.8
	×										×	×			×	433	7.6
	×										×	×		×		1,078	18.9
	×										×		×		×	1,626	28.5
		×								×		×			×	0	0.0
		×								×		×		×		1	0.0
		×								×			×		×	41	0.7
		×									×	×			×	266	4.7
		×									×	×		×		690	12.1
		×									×		×		×	1,122	19.7
			×							×		×			×	0	0.0
			×							×		×		×		1	0.0
			×							×			×		×	15	0.3
			×								×	×			×	152	2.7
			×								×	×		×		405	7.1
			×								×		×		×	690	12.1
				×						×		×			×	0	0.0
				×						×		×		×		1	0.0
				×						×			×		×	13	0.2
				×							×	×			×	75	1.3
				×							×	×		×		204	3.6
				×							×		×		×	352	6.2
					×					×		×			×	0	0.0
					×					×		×		×		0	0.0
					×					×			×		×	3	0.1
					×						×	×			×	78	1.4
					×						×	×		×		190	3.3
					×						×		×		×	316	5.6
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	24	0.4
						×					×	×			×	225	3.9
						×					×	×		×		557	9.7
						×					×		×		×	884	15.3
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	21	0.4

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×			×	182	3.2
							×				×	×		×		469	8.1
							×				×		×		×	780	13.5
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	42	0.7
								×			×	×			×	367	6.3
								×			×	×		×		851	14.7
								×			×		×		×	1,281	22.2
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	27	0.5
									×		×	×			×	235	4.0
									×		×	×		×		595	10.2
									×		×		×		×	968	16.6

Table 5-12. Results for ultra-urban land use for scenario to suspend sweeping December 1/Restart March 15

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
×										×		×			×	0	0.0
×										×		×		×		1	0.0
×										×			×		×	39	0.7
×											×	×			×	542	9.2
×											×	×		×		1,245	21.2
×											×		×		×	1,775	30.2
	×									×		×			×	0	0.0
	×									×		×		×		1	0.0
	×									×			×		×	39	0.7
	×										×	×			×	542	9.2
	×										×	×		×		1,245	21.2
	×										×		×		×	1,775	30.2
		×								×		×			×	0	0.0
		×								×		×		×		1	0.0
		×								×			×		×	29	0.5
		×									×	×			×	210	3.6
		×									×	×		×		577	9.8
		×									×		×		×	954	16.2
			×							×		×			×	0	0.0
			×							×		×		×		1	0.0
			×							×			×		×	16	0.3
			×								×	×			×	137	2.3
			×								×	×		×		368	6.3
			×								×		×		×	632	10.8
				×						×		×			×	0	0.0
				×						×		×		×		0	0.0
				×						×			×		×	3	0.1
				×							×	×			×	86	1.5
				×							×	×		×		227	3.9
				×							×		×		×	392	6.7
					×					×		×			×	0	0.0
					×					×		×		×		1	0.0
					×					×			×		×	12	0.2
					×						×	×			×	59	1.0
					×						×	×		×		163	2.8
					×						×		×		×	282	4.8
						×				×		×			×	0	0.0
						×				×		×		×		0	0.0
						×				×			×		×	11	0.2
						×					×	×			×	148	2.5
						×					×	×		×		398	6.8
						×					×		×		×	662	11.3
							×			×		×			×	0	0.0
							×			×		×		×		0	0.0
							×			×			×		×	11	0.2

Frequency										Technology		Parking Density		Parking Restriction		RPSLY	PSYPR
2PW	1PW	1P2W	1P4W	1P8W	1P12W	S1	S2	S3	S4	MBC	VAC	Ext	Non	Yes	No	lbs/yr	%
							×				×	×			×	126	2.2
							×				×	×		×		347	5.9
							×				×		×		×	598	10.2
								×		×		×			×	0	0.0
								×		×		×		×		0	0.0
								×		×			×		×	27	0.5
								×			×	×			×	271	4.6
								×			×	×		×		654	11.1
								×			×		×		×	1,018	17.3
									×	×		×			×	0	0.0
									×	×		×		×		0	0.0
									×	×			×		×	13	0.2
									×		×	×			×	171	2.9
									×		×	×		×		457	7.8
									×		×		×		×	767	13.1

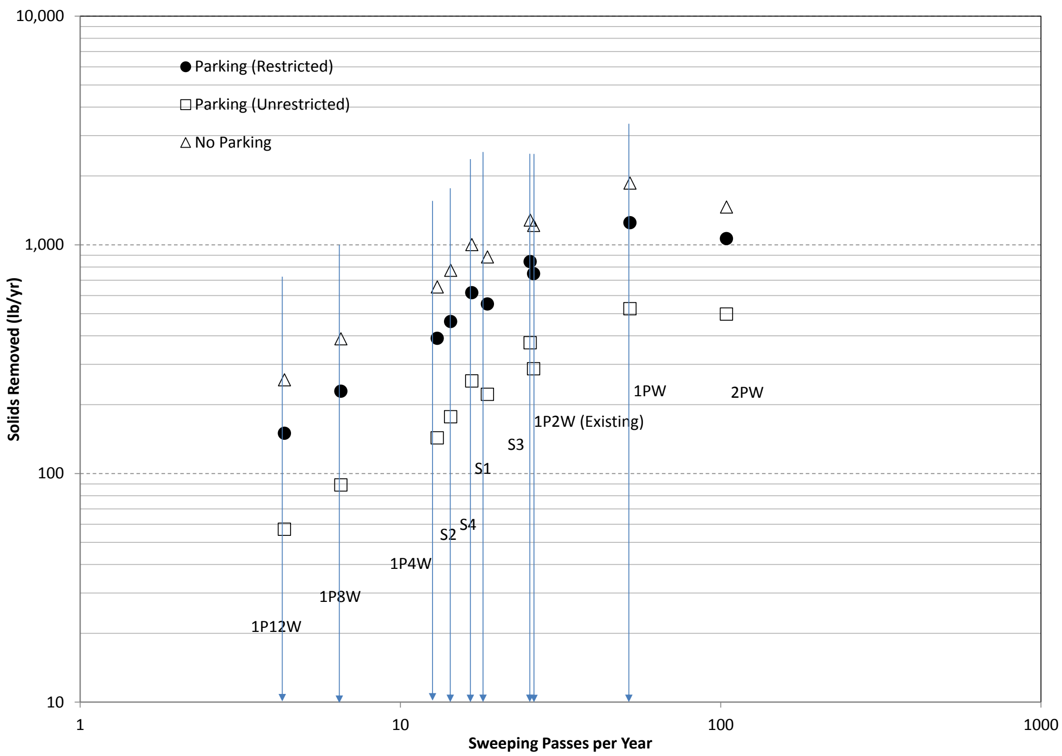

Figure 5-8. Ultra-Urban solid removal rates for different sweeping frequencies and parking restrictions.

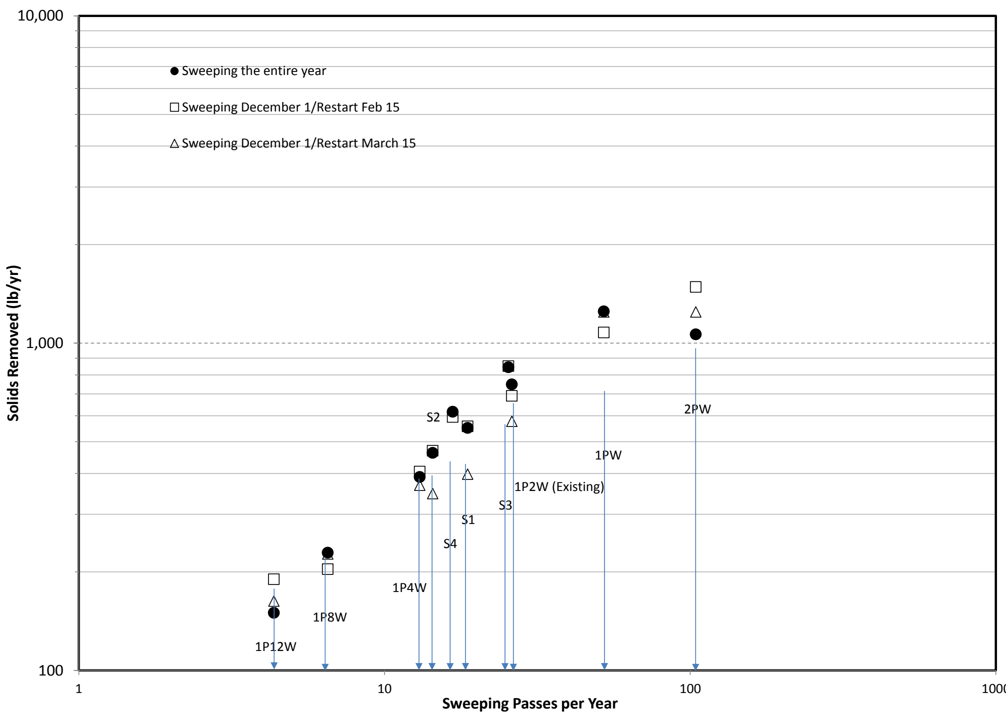

Figure 5-9. Ultra-urban solid removal rates for different sweeping frequencies and winter stops.

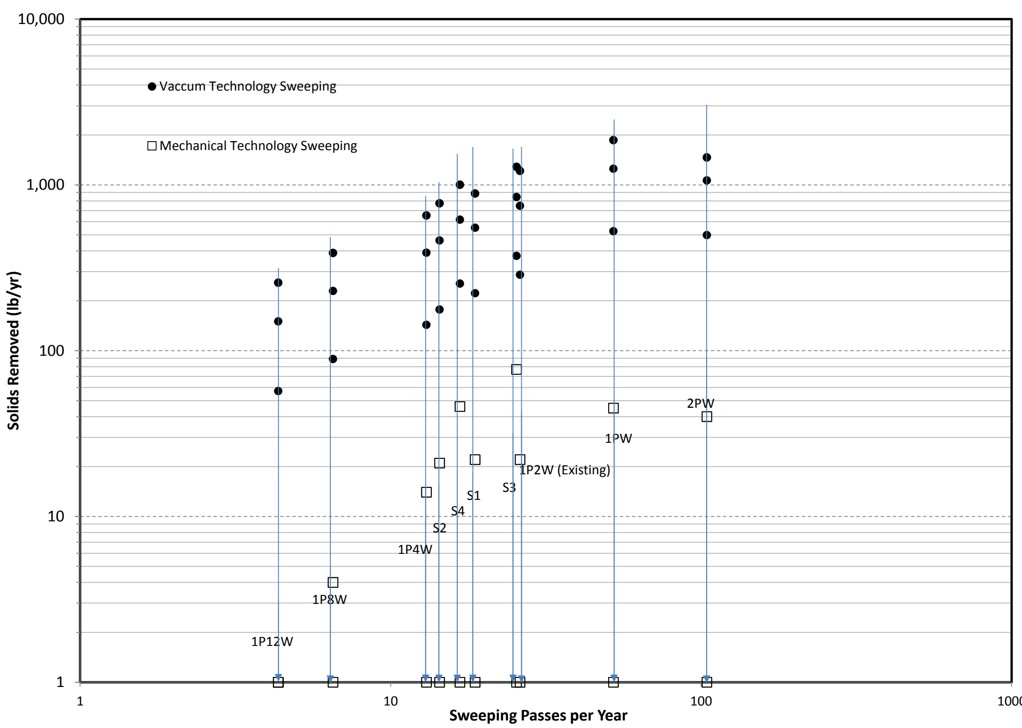

Figure 5-10. Ultra-urban solid removal rates for different sweeping frequencies and technologies.

Table 5-13 shows a summary of the maximum solids yield reductions by land use. The most and least intensive and the current cleaning scenario are highlighted. Note that the S3 scenario achieves greater average reductions than the current BMP, but with one less pass per year. Figure 5-11 also depicts the maximum percent solids reduction in the order of average number of passes per year.

Table 5-13. Maximum percent yield reduction of particulate solids by land use

Cleaning Scenario	Average # Pass/Yr	Residential	Commercial	Arterial	Ultra Urban
1P12W (Least Intensive)	**4**	**5%**	**3%**	**6%**	**6%**
1P8W	7	6%	3%	7%	7%
1P4W	13	11%	7%	12%	12%
S2	14	12%	8%	15%	14%
S4	17	19%	13%	19%	17%
S1	19	14%	9%	16%	16%
S3	25	20%	13%	24%	22%
1P2W (Current BMP)	**26**	**19%**	**11%**	**23%**	**21%**
1PW	52	30%	16%	35%	32%
2PW (Most Intensive)	**104**	**38%**	**20%**	**45%**	**37%**

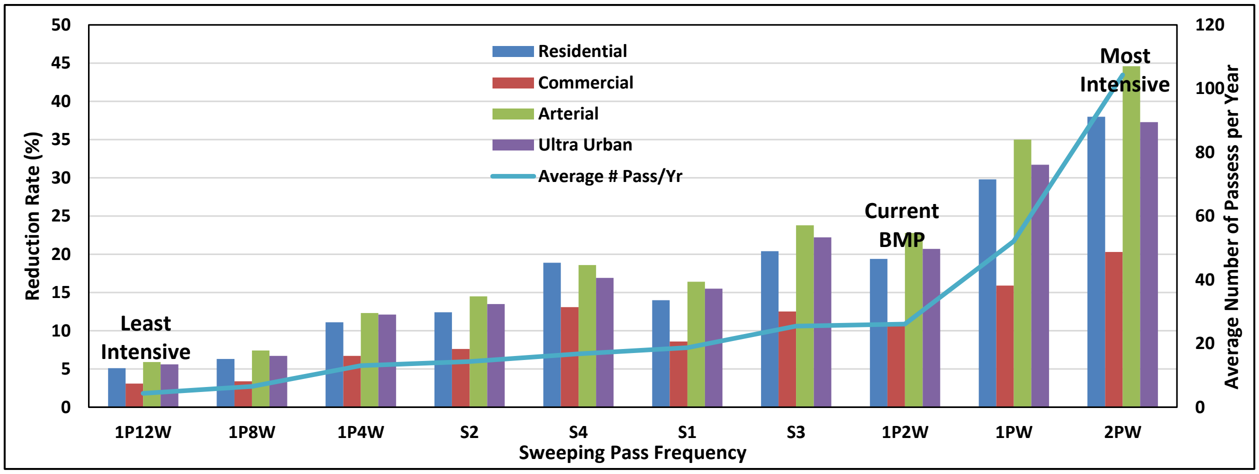

Figure 5-11. Maximum percent solids yield reduction in order of average number of passes.

Table 5-14 shows an example cost-to-benefit ratio for different sweeping passes. The table uses a cost of $1,000 per sweeping pass for example purposes only to help show the relative differences between the scenarios and land uses. Figure 5-12 also shows the cost-to-benefit ratio in order of the sweeping passes numbers. The most and least intensive and the current BMP cleaning scenario are highlighted.

Table 5-14. Cost-to-Benefit ratios for different sweeping frequencies ($1,000 per sweeping pass)

Cleaning Scenario	Average # Pass/Yr	Residential	Commercial	Arterial	Ultra Urban
1P12W (Least Intensive)	**4**	**$852**	**$1,645**	**$525**	**$1,054**
1P8W	7	$1,035	$1,853	$459	$1,104
1P4W	13	$1,174	$1,657	$545	$1,017
S2	14	$1,158	$1,632	$524	$1,074
S4	17	$884	$1,443	$704	$1,101
S1	19	$1,336	$1,628	$524	$1,058
S3	25	$1,247	$1,632	$525	$1,072
1P2W (Current BMP)	**26**	**$1,344**	**$1,764**	**$482**	**$1,101**
1PW	52	$1,750	$1,874	$454	$1,104
2PW (Most Intensive)	**104**	**$2,744**	**$1,872**	**$455**	**$1,196**

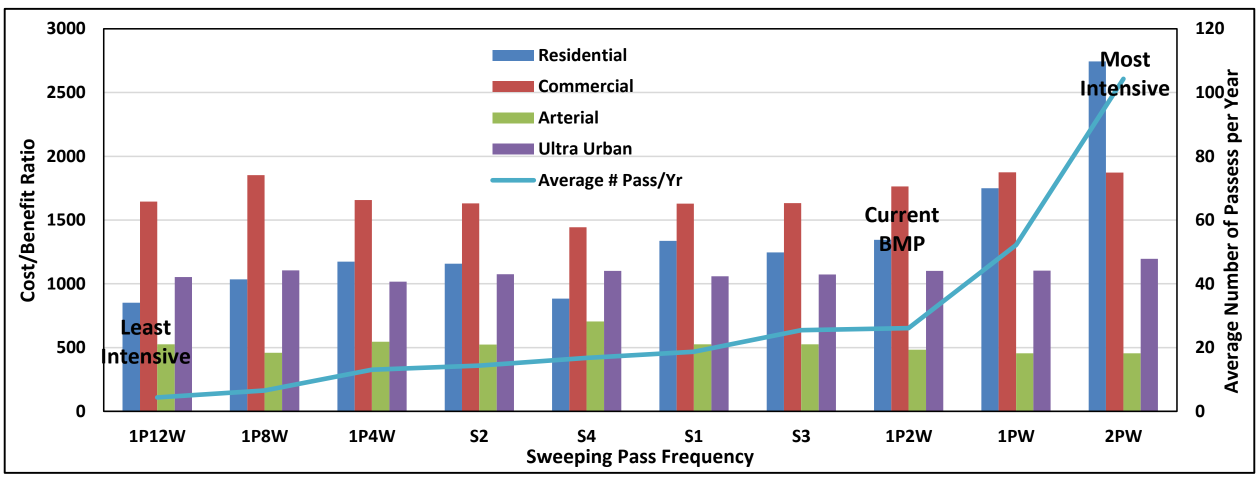

Figure 5-12. Cost-to-Benefit ratios for different sweeping frequencies in order of average number of passes (1 pass expense is $1,000).

5.0 CONCLUSIONS

- Mechanical broom efficiency is very low compared to the vacuum cleaning technology. WinSLAMM assumes that mechanical brooms push the dirt from the middle of the street to the curb. With mechanical brooms, dirt sweeping happens only with the dirt is against the curb however, vacuum sweepers can gather the particles throughout the swept area.

- The highest pollution reduction rate is by applying the most intensive cleaning frequency (2 pass per week).

- A four-fold increase in the existing cleaning frequency (1 pass every two weeks) to the maximum analyzed frequency (2 pass per week) can approximately double the load reduction rate in all the four land uses.

- Of all the tested seasonal cleaning scenario frequencies, S3 (one pass every week in spring, March to April and fall, October to November, and monthly otherwise) provides the maximum load reduction rate.

- Overall, increasing the number of sweeping passes results in increasing sediment removal, but efficiency declines as the number of passes per year becomes large.

- For seasonal scenarios, S4 shows better reduction efficiency versus S1, although S1 average pass numbers per year is higher.

- The analyses presented here investigated only extensive parking and no parking conditions. As described in Bob Pitt's research (Appendix B), high-density parking conditions result in much of the street dirt remaining in the roadway and not at the curb, decreasing street-sweeping efficiency. Greater efficiencies are likely to be obtained under moderate parking density conditions, which were not analyzed in this study.

- Analysis of the seasonal strategies using the number of sweeping passes as a surrogate for operational costs suggests that scenario S4 has the lowest cost-to-benefit ratio for residential and commercial land uses. For the arterial land use, the three seasonal land scenarios S1, S2 and S3 show approximately the same cost-to-benefit ratio and have a ratio smaller than S4. For ultra-urban land use, S1 scenario provides slightly lower benefit-to-cost ratios than the other seasonal scenarios.

- Analysis of all ten scenarios using the assumption that the number of sweeping passes is directly proportional to the operational cost, suggests that scenarios 1P12W, S4, 1PW and 1P4W provide the lowest cost-to-benefit ratios for residential, commercial, arterial, and ultra-urban land uses respectively.

6.0 REFERENCES

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APPENDIX A: WinSLAMM Small Scale Hydrology

WinSLAMM Version 10 Runoff Volume, Total Suspended Solids and Other Pollutant Calculations and Regional Calibration Files

APPENDIX B: Bob Pitt Research Paper

Street Dirt Accumulation, Washoff and Street Cleaning Functions