Recommendations of the Expert Panel to Define Removal Rates for Street and Storm Drain Cleaning Practices

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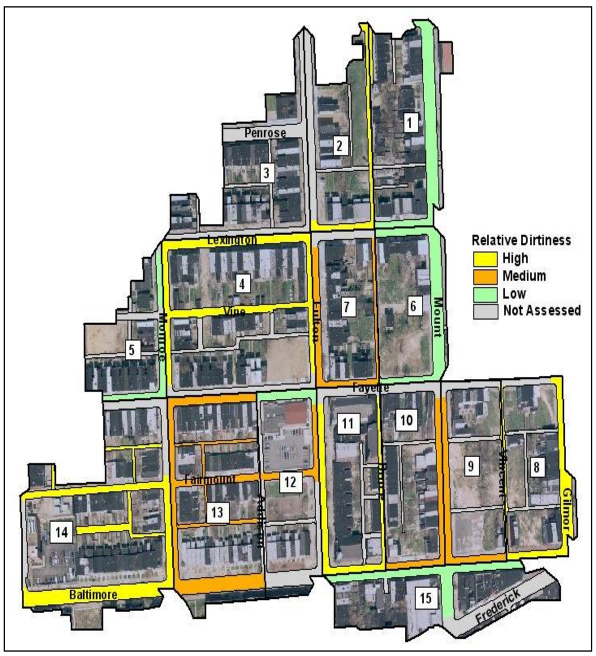
FINAL REPORT



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The following is a list of common acronyms used throughout the text:

ADT	Average Daily Traffic Volume
BMP(s)	Best Management Practice(s)
CBP or CBPO	Chesapeake Bay Program Office
CBWM	Chesapeake Bay Watershed Model
EMC	Event Mean Concentration
HUC	Hydrologic Unit Code
MS4	Municipal Separate Storm Sewer System
NEIEN	National Environmental Information Exchange Network
NPDES	National Pollutant Discharge Elimination System
Rv	Runoff Coefficient
SOP	Standard Operating Procedure
STAC	Scientific and Technical Advisory Committee
TMDL	Total Maximum Daily Load
TN or N	Total Nitrogen
TOC	Total Organic Carbon
TP or P	Total Phosphorus
TSS	Total Suspended Solids
USWG	Urban Stormwater Work Group
WinSLAMM	Source Loading and Management Model for Windows
WIP	Watershed Implementation Plan
WQGIT	Water Quality Goal Implementation Team

Summary of Panel Recommendations

An expert panel was formed in 2013 to re-evaluate how sediment and nutrient removal credits are calculated for street and storm drain cleaning, which is an existing BMP approved by the CBP partnership.

While street cleaning is a common municipal practice across the Chesapeake Bay watershed, it is not widely used at the present time for pollutant reduction, given that most communities either do not sweep frequently enough or use ineffective sweeper technology.

The panel reviewed new research conducted over the last ten years on (a) nutrient and sediment loading from streets, roads and highways (b) the particle size distribution and nutrient, carbon and toxic enrichment of urban street dirt and sweeper waste, and (c) ten recent research studies that evaluated the effect of different street sweeping scenarios on different street types across the country. Based on this review, the panel concluded:

- Road runoff has moderately higher nitrogen concentrations than other forms of impervious cover, and merits its own land use in Phase 6 of the Chesapeake Bay Watershed Model (CBWM).

- The accumulation rate, particle size distribution and pollutant content of street solids follows a relatively consistent and uniform pattern across the nation. These relationships provide a strong empirical basis for modeling how solids are transported from the street to the storm drain.

- Street cleaning may be an excellent strategy to reduce the toxic inputs from urban portions of the Chesapeake Bay watershed, given the high level of toxic contaminants found in street solids and sweeper wastes.

- The water quality impact associated with street cleaning will always be modest, even when it occurs frequently. Mechanical broom sweepers have little or no water quality benefit. Advanced sweeping technologies, however, show much higher sediment reduction potential.

- Street parking and other operating factors can sharply reduce sweeper pick-up efficiency.

- The adjacent tree canopy influences the organic and nutrient loads on the street on a seasonal basis, but the management implications for this phenomenon are unclear. Future panels should revisit this concept as more monitoring data becomes available.

- The ten sweeper studies published since 2006 have produced a lot of quantitative data on the sediments and nutrients that are picked up by sweepers, but none were able to measure a detectable water quality change within storm drains that can be attributed to upland street cleaning. One key reason is the high variability that often occurs in street runoff can outweigh a measurable signal due to street cleaning. To date, researchers have been unable to collect enough paired stormwater samples to overcome this variability detect a statistically significant difference due to treatment. Consequently, most researchers now rely on simulation or mass balance models to quantify the impact of street cleaning.

The panel agreed that modeling was the best available approach to derive sediment and nutrient reduction rates associated with street cleaning. The panel elected to use the WinSLAMM model, and supervised the work of a consultant to develop a Chesapeake Bay application of the model. The model was selected because it has (a) a module to assess sediment reduction for a wide range of street cleaning scenarios, (b) been calibrated to empirical data on street solid build-up and wash-off and (c) been used to estimate pollution reduction credits for street cleaning for TMDLs in two states.

The panel used the model output from the Chesapeake Bay version of WinSLAMM to develop its protocol for calculating sediment and nutrient reductions associated with different street cleaning scenarios. The model was used to simulate the expected annual sediment reduction for 960 different street cleaning scenarios, which included 3 different lengths for winter shutdown, 4 types of streets, 2 sweeper technologies, 10 different cleaning frequencies, and 4 combinations of street parking conditions and controls. A spreadsheet tool was used to define percent nutrient removal rates by applying a nutrient enrichment ratio to mass of sediments removed per acre in each street cleaning scenario, and subtracting the resulting nutrient load from the unit area nutrient load for impervious cover calculated by the watershed model.

Pollutant Reductions Associated with Different Street Cleaning Practices					
Practice #	Description [1]	Approx Passes/Yr [2]	TSS Removal (%)	TN Removal (%)	TP Removal (%)
SCP-1	AST- 2 PW	~100	21	4	10
SCP-2	AST- 1 PW	~50	16	3	8
SCP-3	AST- 1 P2W	~25	11	2	5
SCP-4	AST- 1 P4W	~10	6	1	3
SCP-5	AST- 1 P8W	~6	4	0.7	2
SCP-6	AST- 1 P12W	~4	2	0	1
SCP-7	AST- S1 or S2	~15	7	1	4
SCP-8	AST- S3 or S4	~20	10	2	5
SCP-9	MBT- 2PW	~100	0.7	0	0
SCP-10	MBT- 1 PW	~50	0.5	0	0
SCP-11	MBT- 1 P4W	~10	0.1	0	0

AST: Advanced Sweeping Technology MBT: Mechanical Broom Technology
[1] See Table 15 for the codes used to define street cleaning frequency
[2] Depending on the length of the winter shutdown, the number of passes/yr may be 10 to 15% lower than shown

For the sake of simplicity, the panel elected to consolidate the model results to show removal rates for eleven different street cleaning practices, primarily involving the use of different street cleaning technology at different frequencies, as shown in the preceding table.

In general, one impervious acre is equivalent to one curb-lane mile swept for streets with curbs and gutters. The street sweeping credit is an annual practice, so communities need to submit the total number of curb lane miles swept under the appropriate street cleaning scenario.

The panel recommended that MS4 communities report their annual street cleaning effort in the annual MS4 reports they submit to the state stormwater agency. Localities will also need to maintain records to substantiate their local street cleaning effort (e.g., length of routes swept, frequency, sweeper technology and parking conditions/controls, etc.).

In addition, the panel recommended a strong verification program to document local street cleaning effort over time and provide additional data on sweeper waste characteristics. Localities will need to track the mass of selected hopper loads to verify the aggregate mass of solids that are picked up through their street cleaning program.

To reduce the local verification burden, the panel recommended that communities could sub-sample hopper loads to estimate the aggregate mass of solids captured. The panel also encouraged MS4 communities to perform periodic nutrient sampling of sweeper wastes.

The panel also recommended a second sediment and nutrient removal credit for solids that are directly removed from catch basins, within storm drain pipes or are captured at the outfall. The sediment credit is based on the dry weight of the mass of solids captured and removed, whereas the nutrient reduction is determined by multiplying the mass of solids by a default nutrient enrichment factor.

The storm drain credit rewards innovative efforts to manage sediment and organic matter that reaches the storm drain system and therefore has a much higher chance of being transported downstream to the Bay.

The panel established three qualifying conditions to ensure that the storm drain cleaning efforts have a strong water quality focus.

1. To maximize load reduction, efforts should be targeted to focus on catch basins trapping the greatest organic matter loads, streets with the greatest adjacent tree canopy and/or outfalls with highest sediment or debris loads.

2. The load removed must be verified using a field protocol to measure the mass or volume of solids collected within the storm drain pipe system. This may also entail periodic sub-sampling of the carbon/nutrient content of the solids.

3. Material must be properly disposed so that it cannot migrate back through the watershed

The panel agreed that the two existing methods for calculating pollutant reduction achieved by street cleaning by the 2011 panel should be phased out. The existing "qualifying lane miles method" in Appendix A should be replaced by the more versatile credit proposed by this expert panel as soon as possible. The existing "mass loading method" for street cleaning may continue to be used until 2017, but should be completely phased out when the Phase 6 Chesapeake Bay Watershed Model becomes operational in 2018.

The panel also recommended a long term research strategy to provide managers with the key data to improve the effectiveness of future street and storm drain cleaning programs. In addition, the panel outlined several priorities to build up the capacity of existing programs to implement more effective programs that maximize pollutant reduction to local waterways and the Chesapeake Bay.

The panel also endorsed the creation of a new land use in Phase 6 of the Chesapeake Bay Watershed Model that represents the impervious cover associated with transport land uses (i.e., streets, roads and highways).

Section 1: Charge and Membership of Expert Panel

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An expert panel recommended sediment and nutrient removal rates associated with intensive street sweeping in 2011 (CSN, 2011), largely based on the research and literature review provided by Law et al (2008). However, the recommendations were made prior to the adoption of a uniform BMP review protocol, as outlined by the Water Quality Goal Implementation Team (WQGIT, 2014). In particular, the four page memo produced by the 2011 panel did not contain detailed recommendations on how to report, track and verify the practice for credit in the Chesapeake Bay Watershed Model (CBWM), nor did it document the full body of research used to derive the recommended rates.

In addition, many localities requested that the panel broaden its scope to include more activities that remove sediments and vegetative debris from the storm drain system, such as catch basin cleanouts, municipal leaf collection, and the use of nets and screens to capture urban detritus at the outfalls of storm drain pipes. At the same time, researchers have conducted more monitoring on the performance of the next generation of street sweepers, as well as the nutrient content of sediment and detritus at various points of the street and storm drain system. Several protocols for defining nutrient and sediment removal rates for these practices have been developed in response to several TMDLs in northeastern states which may be applicable, in part, to the Chesapeake Bay watershed.

A wide range of local and state stakeholders agreed at a session of the 2012 Bay-wide stormwater retreat that the expert panel should be re-convened and the BMP expanded in scope to address the above cited issues, and provide more options for localities to get verifiable credits for more active management of their street and storm drain network.

The initial charge of the panel was to review all of the available science on the nutrient and sediment removal performance associated with the active cleaning of municipal street and storm drain infrastructure:

1. Street cleaning, with an emphasis on new developments in sweeper technology and operation.
2. Targeted catch basin cleaning to prevent nutrient and sediment deposits from migrating further down the storm drain system.
3. Municipal biomass (leaves, grass clippings etc) collection programs to keep detritus out of the street and storm drain system.
4. The use of nets, screens and other devices to capture urban detritus from stormwater outfalls prior to its delivery to receiving waters.

The panel was specifically requested to assess:

- The technical assumptions underlying the 2011 memo, along with its supporting research and literature review provided in Law et al (2008).

- New street cleaning research from 2007 to the present, including USGS studies in MA, WI and elsewhere.

- The potential for credits for less frequent street cleaning frequencies than recommended by the original panel (26 times per year).

- The technical support for pollutant reduction protocols for the four practices developed in other regions of the country.

- Studies measuring the nutrient content of sediment and leaf detritus at various points in the urban landscape.

- Provide a specific operational definition for each of the four management practices defined earlier and recommend the qualifying conditions under which a locality can receive a nutrient and/or sediment reduction credit.

- Evaluate whether the existing CBP approved nutrient removal rates for street sweeping in 2011 are reliable, and recommend appropriate procedures and units for reporting, tracking, and verification of the practice.

Beyond this specific charge, the panel was asked to:

- Evaluate whether the current procedures for simulating the wash-off of sediments and nutrients from impervious cover in the CBWM accurately reflect how sediments and vegetative detritus move through the storm drain system, and whether or not future versions of the CBWM may need a land use or land cover that better represents street and highway conditions.

- Take an adaptive management approach to refine the accuracy of its removal rate protocol, including any recommendations for further monitoring research that would fill critical management gaps.

- Critically analyze any unintended consequences associated with the nutrient management credit and any potential for double or over-counting of the credit.

While conducting its review, the panel followed the procedures outlined in the BMP review protocol, as amended (WQGIT, 2014). The process begins with BMP expert panels that evaluate existing research and make initial recommendations on removal rates. These, in turn, are reviewed by the Urban Stormwater Workgroup, and other Chesapeake Bay Program (CBP) committees, to ensure they are accurate and consistent with the Chesapeake Bay Program partners' Watershed Model (CBWM) and associated tools.

Appendix C describes this report's conformity to the BMP review protocol (WQGIT, 2014). Minutes from the Panel's conference calls are provided as Appendix D.

Section 2: Key Definitions

The analysis of street and storm drain cleaning practices draws on varying terminology from the scientific and practitioner communities. To assist the reader, the panel agreed to the definitions provided below to maintain consistency throughout the report.

Street Sweeping vs. Street Cleaning: Both terms are used interchangeably in the literature to describe the use of sweepers to pick up solids off the street surface. In the context of this report, street sweeping is used to denote the more historic approach to the practice (i.e., use of mechanical broom sweepers to improve street aesthetics and safety). The term "street cleaning" refers to the more specific practice that uses advanced sweeper technologies to improve water quality.

Solids Terminology:

- *Street Dirt*: the total mineral fraction of street solids of all grain sizes (clay to gravel), expressed in lbs/curb mile
- *Street Detritus*: the total organic fraction of street solids, typically comprised of leaves, grass clippings, pollen and other biomass
- *Street Solids*: The total mass of street dirt and detritus, as measured on the street surface, catch basin or sweeper hopper
- *Gross Solids:* Total mass of non-organic solids larger than gravel size, which represents trash and litter, and may be subject to a trash TMDL.

Solids Particle Size:

Although some differences exist among the cutoff thresholds in the literature, the following general definition was adopted.

- *Coarse-Grained Solids*: All particles greater than 1000 microns in diameter
- *Medium-Grained Solids*: All particles from 75 microns to 1000 microns in diameter
- *Fine-Grained Solids*: All particles less than 75 microns in diameter.

Street Sweeper Technology

- *Mechanical Broom Sweepers (MBS)*: Sweeper is equipped with water tanks, sprayers, brooms, and a vacuum system pump that gathers street debris
- *Regenerative-Air Sweepers (RAS):* Sweeper is equipped with a sweeping head which creates suction and uses forced air to transfer street debris into the hopper.

- *Vacuum Assisted Sweepers (VAS):* Sweeper is equipped with a high power vacuum to suction debris from street surface.

Note: For purposes of this report, the RAS and VAS sweepers both qualify as Advanced Sweeper Technologies (AST) and achieve higher pollutant removal rates, whereas MBS sweepers do not, and do not provide any pollutant removal.

Yields/Rates:

- *Catch Basin Accumulation Rate*: the mass, dry weight, of trapped solids over a defined time step, measured in lbs.

- *Street Solids Yield*: the mass, dry weight, of street solids, measured on the street before or after sweeping, expressed in terms of lbs/curb mile.

- *Sweeper Waste Yield*: the mass, dry weight, of street solids collected by a street sweeper, expressed in terms of tons.

- *Pick-up Efficiency:* The fraction of the available solids on the street that is effectively removed by a street sweeper, expressed as a percent, which varies based on sweeper technology.

- *Nutrient Enrichment Ratio*: Extractable nutrients found in either street solids or sweeper wastes, originally measured in mg/kg or lbs/ton, but converted to a percentage and applied to the effective sediment reduction rate to estimate nutrient reduction for different street cleaning scenarios.

- *Effective Sediment Reduction Rate:* the percent reduction in the unit area sediment loading rate associated with a qualifying street cleaning practices, as predicted by the WinSLAMM model. The sediment percent removal is then applied to the unit area sediment load for impervious cover derived by CBWM to determine the mass reduced.

Other Key Terms:

- *Average Daily Traffic (ADT):* a measure of the traffic volume on a street, road or highway, expressed in vehicles per day. ADT is often used to classify streets, and distinguish between urban versus rural roads.

- *C:N:* The elemental ratio of carbon to nitrogen in vegetation and street detritus. The lower the ratio, the more N is potentially available. Freshly fallen leaves have a C:N ratio of about 60, but this drops to about 40 as they decompose (i.e., leaf compost), and fall to about 15 for grass clippings.

Section 3: Background on Street Cleaning in the Bay Watershed

3.1 Prevalence of Street Cleaning in the Chesapeake Bay

Our best understanding about local street cleaning programs comes from a detailed survey of 36 municipalities, most of which were located in the Chesapeake Bay Watershed (CWP, 2006b). This section summarizes the survey's key findings, although it should be noted that local street and storm drain cleaning practices may have changed in the decade since the survey was conducted.

The first finding is that nearly all communities operate some form of street sweeping program. The survey indicated that aesthetics and public demand were the main drivers for local street sweeping programs, with only one community citing nutrient removal as a major objective. Some of the key factors that determine which streets are swept include high traffic volume, residential demand, commercial areas, central business districts and proximity to environmentally sensitive areas (Table 1).

Table 1. Factors to select streets for enrollment in street sweeping program and sweeping frequency (n=20). Expressed as % of communities**.** CWP, 2006b

	Traffic volume	Land use	Target commercial areas	Residential demand	Proximity to ESA [1]	Loading rates
Street selection	45%	5%	45%	40%	10%	5%
Frequency	30%	5%	35%	35%	10%	5%

[1]. **ESA = environmentally sensitive area**

Municipal sweeping programs vary widely in their size and scope. The survey found communities sweep at least 70% of their public streets at least once a year, and that 85% of communities swept a subset of their streets more frequently. The proportion of streets that are swept ranged from 6% to 100% of all publicly owned streets. Some communities sweep streets in early spring to remove sand and other material that is applied during winter snow removal operations. By contrast, fewer communities target sweeping efforts in the fall to pickup leaf detritus from their streets.

Less than 25% of the communities surveyed clean their streets frequently enough to qualify for the pollutant removal credits approved by CBP in 2011 (and then for only a smaller subset of their overall street network). Figure 1 summarizes the variability in sweeping frequency by communities that clean their streets more than once a year.

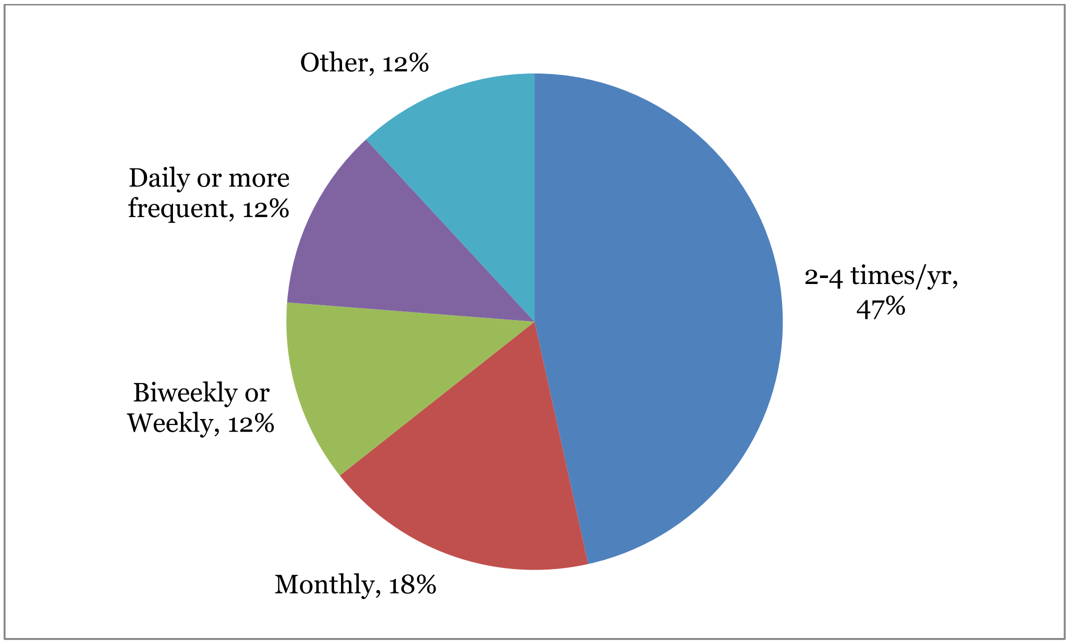


Figure 1. Percentage of communities that sweep more than once per year and the associated sweeping frequency (n=17) Source: CWP, 2006b

Street sweeper technology can have a strong influence on sediment pick-up efficiency. Newer technology, such as vacuum-assisted sweepers or regenerative air sweepers have better pickup efficiency than older mechanical broom sweepers. However, as of 2006, only 27% of the municipalities reported that they employed advanced street cleaning technology (Figure 2).

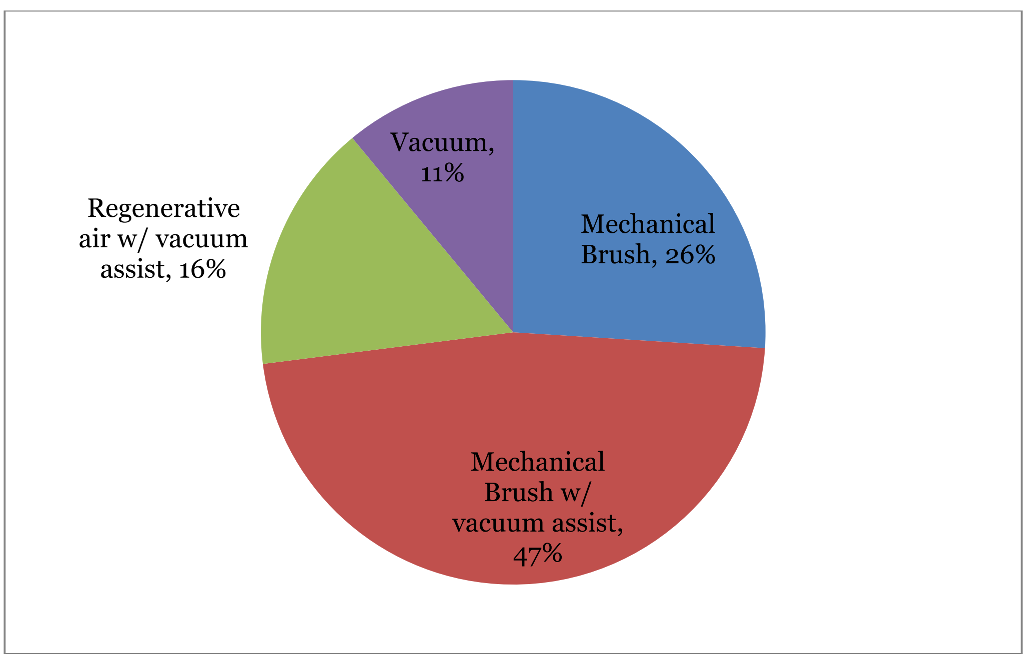


Figure 2. Most common street cleaning technology used by Chesapeake Bay communities (n=19) Source: CWP, 2006b

3.2 Catch Basin Cleanouts

The CWP survey also looked at how frequently communities performed storm drain cleanouts (CWP, 2006b). The key finding was that only 40% of Bay communities scheduled regular cleanouts while the rest only did them in response to public complaints or actual flooding problems. Communities tend to conduct storm drain cleanouts infrequently, with only 6% cleaning them out once a year (Table 2). Improving water quality has not been an objective of local storm drain cleanout programs.

Table 2. Storm drain cleanout frequency in the Chesapeake Bay (n=19)

Frequency	Percent
Seldom, if ever	23.5
Once every 3-4 years	29.4
Every 2 years	23.5
Annual	5.9
Twice a year	0
Other	17.6

3.3 Past CBP Street Cleaning Removal Credits

Appendix A summarizes the two methods for crediting street cleaning developed by the 2011 expert panel. The first method is termed the **mass loading approach**, and calculates sediment and nutrient removal based on the mass picked up by the sweeper fleet, with an adjustment for particle size. The second method is termed the **qualifying lane miles approach,** and calculates the load reduced based on the aggregate acres of road that are swept in a community that meet the qualifying conditions.

Both methods only apply to streets that are swept biweekly (26 times per year) or more frequently. For that reason, relatively few communities in the Bay watershed have reported the street sweeping credit in recent years. The 2011 expert panel did not include any procedures to verify the local street cleaning effort reported to the states for credit. Consequently, there has been a fair amount of confusion about the annual street cleaning effort reported to date.

This is evident in the street cleaning implementation data that the seven Bay jurisdictions submit to the Chesapeake Bay Program each year. As can be seen in Table 3, jurisdictions can report local street cleaning effort in units of either acres swept or pounds collected, or both. To date, five states have reported street cleaning in their annual progress submissions since 2009, although reporting is not consistent or of uniform quality.

Table 3. Summary of Street Cleaning Implementation, 2009-2013, as reported and credited in annual progress runs (acres and lbs)

YEAR	DC	DE	PA	WV	VA
2009	1 ac			218,000 lbs	632 ac
2010	1,631 ac			227,000 lbs	
2011	1,540 ac		619 ac		75,385,792 lbs
2012	1,539 ac		413 ac		
2013	1,526 ac	79,541 lbs	3,240,489 lbs	190,000 lbs	218,677 lbs
2014	1,531 ac	413,367 lbs	3,367,040 lbs	700,000 lbs	426,671 lbs

3.4 How the CBWM Simulates Loads From Streets

The Phase 5.3.2 Chesapeake Bay Watershed Model simulates two types of urban land cover: pervious and impervious. These two cover types are used to simulate the full range of urban land use categories (industrial, commercial, residential, institutional and transport). This means that different street types (e.g., highways, arterials, residential streets) are lumped in with other impervious surfaces (e.g., driveways, sidewalks, rooftops, parking lots), and are currently represented as a single impervious layer. As a result, streets and roads do not load differently and are not counted separately in the current version of the CBWM. Table 4 portrays the average annual nutrient and sediment loadings associated with urban impervious cover in the current model.

Table 4. Loading Rates Associated with Urban Impervious Cover in the Chesapeake Bay Watershed Model, Version 5.3.2.

Acres in Watershed [1]	1,269,030
Average TN Load [2]	15.5 lbs/ac/yr
Average TP Load [2]	1.93 lbs/ac/yr
Average TSS Load [2]	0.65 t/ac/yr
Key Inputs	Air Deposition, Build-up/Wash-off, No Groundwater Interaction, No Direct Interaction with Pervious Cover

[1] Acres, as reported in most recent CBWM version 5.3.2
[2] Average values, as reported in Tetra Tech (2014), although actual values are regionally variable across the watershed.

It should be noted that not all of the sediment load generated from urban impervious cover actually reaches the Chesapeake Bay. The sediment loads at the edge of pavement are adjusted downward by a sediment delivery factor in the current version of the CBWM. For a more thorough discussion of the sediment delivery factor, please consult the discussion in SR EP (2014).

Section 4: Review of the Available Science on Street Cleaning

The expert panel reviewed more than 100 research papers during its deliberations. The major focus was on studies published after the last literature review used by the previous expert panel (CWP, 2006b). The national review focused on research that investigated:

(a) nutrient and sediment loading from streets, roads and highways

(b) the particle size distribution of urban street dirt and sweeper wastes, as well as their nutrient, carbon and toxic content, and,

(c) the effect of different street sweeping scenarios on different street types across the country.

4.1 Nutrient and Sediment Concentrations in Road Runoff

The panel first investigated whether the nutrient and sediment concentrations in road runoff were different compared to other urban land uses or types of impervious cover. The panel relied on a recent re-analysis of the National Stormwater Quality Database (NSQD, Pitt, 2014) provided by Tetra Tech (2014). Over the last decade, the NSQD has roughly doubled in size, and now includes more than 8,000 storm event samples.

Some of the key findings from the analysis are shown in Figure 3, which compares the TN concentrations in stormwater runoff measured for different types of impervious cover. The mean TN concentration for transport land uses, which includes roads, streets and highways, was 3.11 mg/l, as compared to 1.98 mg/l for all other urban runoff samples. The higher TN concentration for transport land uses was considered statistically significant, based on Wilcoxon rank sum testing (Tetra Tech, 2014). The presumed explanation for the higher TN concentrations at transport land uses is probably related to the close proximity of vehicle emissions.

By contrast, the same analysis showed that TSS and TP concentrations from transport land uses were not statistically different from other urban land uses or impervious cover types. This is evident in the box and whiskers plot shown in Figure 4, which compares TP event mean concentrations for transport versus other urban land uses. As can be seen, there are little or no differences in TP concentration among the different urban land uses.

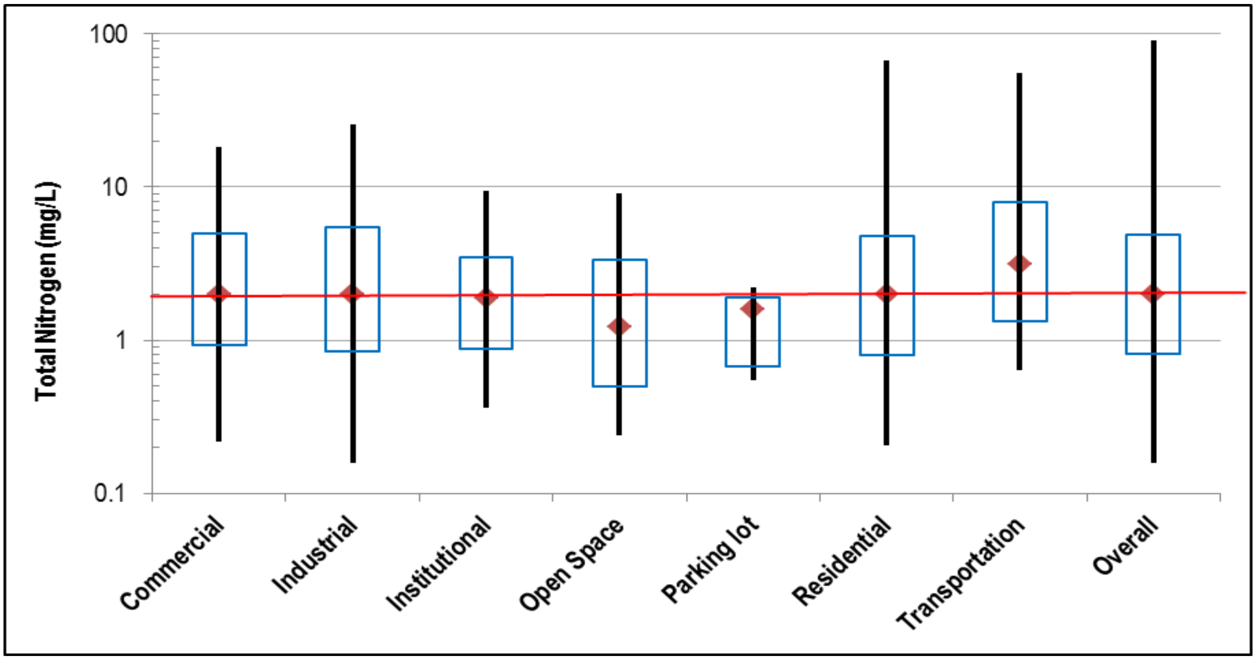


Figure 3. TN Event Mean Concentration for Various Urban Land Uses
Source: Tetra Tech, Inc, 2014.

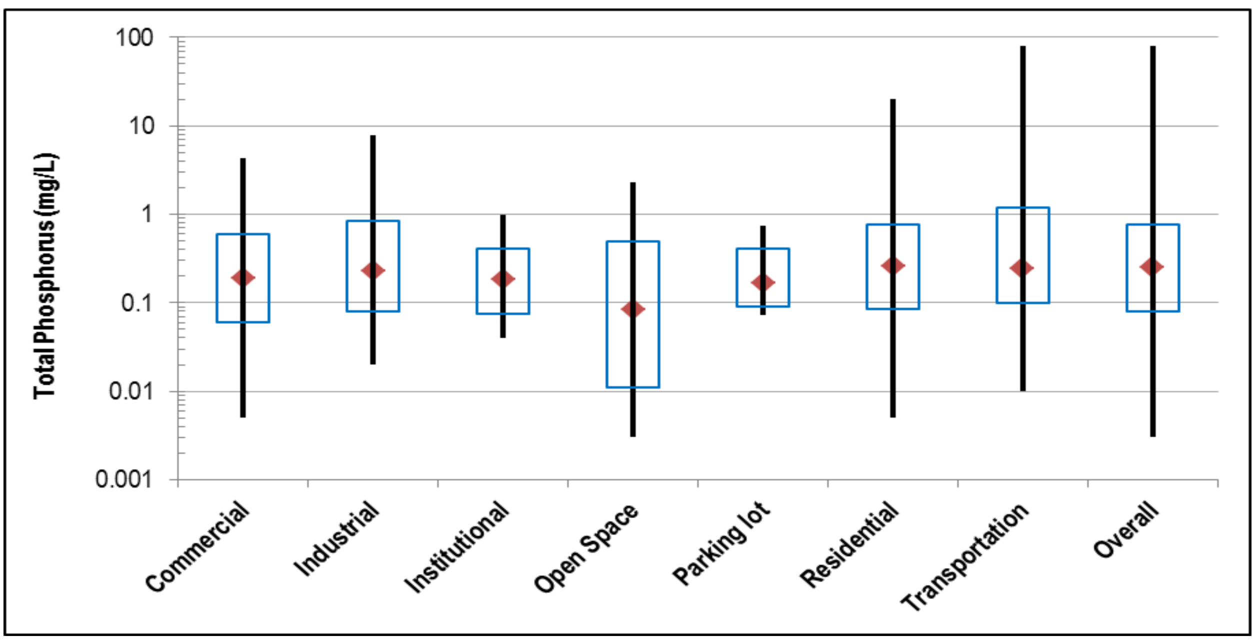


Figure 4 TP Event Mean Concentration for Various Urban Land Uses
Source: Tetra Tech, Inc 2014.

Another key finding was that the average daily traffic volume (ADT) for a street had a moderate influence on measured concentrations of nutrients and sediment in stormwater runoff. Table 5 explores the general relationship of between stormwater EMCs as a function of ADT.

The most pronounced relationship is for TN, which steadily climbs as ADT increases. The relationship for TSS and TP is more mixed, with higher concentrations observed at both low and high ADT streets. Often, low ADT streets lack a curb and gutter to demarcate the road pavement, and instead have turf shoulders, which may become a potential source of solids and organic detritus.

Table 5. Median Stormwater EMCs for Sediment and Nutrients as a Function of ADT

ADT	TSS (mg/l)	TN (mg/l)	TP (mg/l)
High	129	3.48	0.34
Medium	119	2.46	0.21
Low	126	2.17	0.36
Overall	**64**	**2.0**	**0.25**

Source: Tetra Tech, 2014
Overall value refers to all urban land use stormwater samples

4.2 Characterization of Urban Street Solids

Street solids are a complex mix of both mineral sediments and organic detritus that exhibit particle sizes ranging from extremely coarse-grained (larger than 1000 microns) to very-fine grained silts and clays (less than 60 microns). Street solids tend to be carbon and nutrient rich, and are frequently contaminated with petroleum hydrocarbons, trace metals and other pollutants.

Table 6. Comparison of measured street solids yield around the country (Lbs/curb mile--dry weight)

Median Yield	Location	Citation	Note
650 *	Baltimore, MD	Law et al 2008	Ultra Urban
1100 *	Baltimore, MD	Law et al 2008	Ultra Urban/US
350	Seattle, WA	SPU et al 2009	Industrial/RAS
240	Seattle, WA	SPU et al 2009	Resid./RAS
160	Seattle. WA	SPU et al 2009	Resid/RAS
1100	Seattle¸WA	SPU et al 2009	Industrial/US
1010	Seattle. WA	SPU et al 2009	Resid/US
790	Seattle. WA	SPU et al 2009	Resid/US
602	Boston, MA	Sorenson, 2013	Multi-fam. resid
467	Boston, MA	Sorenson, 2013	Commercial
672	Madison, WI	Selbig et al, 2007	Resid/US
455	Madison, WI	Selbig et al 2007	Resid/US
488	Madison, WI	Selbig et al 2007	Resid/US
408*	Champaign, IL	Bender et al 1984	US
391*	Nationwide	Sartor/Boyd 1972	US
705	Bellevue, WA	Pitt and Bissonette, 1984	
Grand Mean: 600 Range: 160-1100			

* indicates a mean value
[1] One curb mile is roughly equivalent to one acre of impervious cover
US = Unswept, RAS= Regenerative Air Sweeper, Resid = Residential

Several recent studies have measured street solids yield (in pounds per curb mile), which is a useful index of solids accumulation on the street surface. Table 6 compares seven studies that have measured street solid yields from around the country. Some variability would certainly be expected, given the inherent difference in street types, land use and climates among the studies. Surprisingly, street solid yield is fairly consistent across the country, with most studies clustering around 400 to 800 lbs/curb mile.

The research indicates that some road types may have higher sediment accumulation rates than others (e.g., residential, industrial, freeway, medians versus curbs), but there have not been enough studies to produce reliable comparative statistics. Some researchers have suggested that residential streets may have higher nutrient concentrations, particularly if they have a significant tree canopy (Ray, 1997, Baker et al, 2014).

Several studies have found that sediment and nutrient accumulation rates differ between streets that have curb and gutters and streets that do not have them (Sorenson, 2013). In general, curbs and gutters create a trap that retains sediment and organic particles where they can be effectively swept. Streets without curb and gutters do not have a trap at the pavement edge, and the adjacent pervious area may become a source of sediment that can be mobilized by contact with a sweeper. For these reasons, the panel concluded that street sweeping could only be effective for streets and roads that possess a curb and gutter.

The panel compared data on the particle size distribution for street dirt across the country, which is presented in Table 7. Once again, the distribution in particle size was surprisingly consistent across the country, with about two-thirds of particles classified as medium-grained (63 to 2000 microns), about 10% as fine-grained (less than 62 microns) and about 20% as coarse-grained.

Table 7. Comparison of General Particle Size Distribution of Street Solids

GRAND MEAN of 9 Studies [1]	**Coarse**	**Medium**	**Fine**
	19.9	**65.3**	**9.2**

* numbers do not add up to 100% due to rounding
[1] See Table A-1 for a full comparison of the nine studies, their citation and particle size cut-off thresholds.

The particle size distribution of street dirt has several important implications related to street cleaning. First, particle size influences the mobility of street solids during runoff events and whether or not they will reach the storm drain system. Coarse-grained particles are more difficult to entrain in stormwater runoff and may take a long time to reach the storm drain system. Second, particle size has a strong influence on the pickup efficiency of street sweepers. In general, sweepers are most effective at picking up coarse-grained particles from the street, and are much less effective at getting to the fine-grained particles (Selbig and Bannerman, 2007).

Lastly, particle size is also strongly related to the degree of nutrient enrichment for street solids. The conventional wisdom is that many of the nutrients are associated with fine-grained street solids (Vaze and Chiew, 2004) as well as the organic fraction of the most coarse grained particles (Waschbusch et al, 1999, Pitt, 1985 and Sorenson, 2013, and Tables 8 and 9). Medium-grained particles, which comprise the greatest fraction of street solids, had the lowest level of nutrient enrichment.

Table 8. TP enrichment in street solids by particle size (mg/kg)

STUDY	COARSE	MEDIUM	FINE
Pitt 1985	1015	600	785
Sorenson, 2013	400	400	800
Sorenson, 2013	800	500	900

Table 9. Percent of pollutants, by mass, in Madison, WI street solids
Source: Waschbusch et al, 1999

	< 63 micron	63-250 micron	> 250 micron	Leaves
Sediment	2.5	15.5	74	8
Total P	5	15	50	30

4. 3 The Organic Fraction of Street Solids

Another key issue relates to the organic fraction of urban street solids. Some recent research suggests that leaf detritus and other organic matter inputs can play an important role in street nutrient loads. Street solids tend to have a relatively high organic carbon content, particularly in the fine and coarse grained fractions (SPU, 2009, Sorenson, 2013). On average, organic carbon comprises about 5 to 12% of the mass of street solids, but this can be even higher following leaf drop (Sorenson, 2012, Kalinosky, 2013, Selbig, 2014).

The panel reviewed a great deal of recent literature on the interaction between leaf detritus, street loads and nutrient dynamics in the urban landscape. Fall leaf drop provides a potentially large "gutter subsidy" in terms of the mass of organic carbon available for wash-off (Kaushal and Belt, 2012, Duan and Kaushal 2013), and to a lesser degree, pollen and green fall during the growing season.

Initially, the C:N ratio of freshly fallen leaves is about 60 or so (Heckman and Kluchinski, 1996). The ratio drops to about 40 as leaves age and decompose, and can be as low as 15 for decomposing grass clippings (Newcomber et al, 2012). Nutrients, especially phosphorus, rapidly leach from fallen leaves and grass clippings after being immersed in water for a few days. Wallace (2008) found grass clippings leached more phosphorus than leaves.

The initial grain size of leaf detritus is more than 1000 microns, but becomes progressively finer grained throughout the year due to physical and mechanical fragmentation and decomposition. Street detritus deposits are not very mobile until intense storms or melt events provide enough energy to move them into the storm drain, although the deposits become progressively finer throughout the year.

Leaf decomposition rates are much faster on pavement than on adjacent natural areas (Hobbie et al, 2013), possibly because of increased moisture in the gutter environment Decomposition rates are rapid for leaves on pavement with 80% loss of initial mass within one year (Hobbie et al, 2013). Baker et al (2014) observed rapid nutrient leaching in the first few days after leaf drop, particularly for phosphorus.

4.4 Nutrient Enrichment of Street Solids and Sweeper Waste

This section summarizes recent research on nutrient enrichment of street solids and sweeper waste. To aid comparison, enrichment values that were reported as mg/kg were converted to a simple percentage applied to mass of solids/sediment (dry weight). Table 10 compares nutrient enrichment measurements taken across the country and shows that the degree of nutrient enrichment measured among the 12 studies was very similar. It should also be noted that the mean nutrient enrichment levels reported in Table 10 are slightly lower than values used in the last expert panel report (which were derived from a single study -- the ultra-urban Baltimore streets monitored by DiBlasi, 2008).

Based on the analysis, the fraction of street solids that is enriched by phosphorus ranges from 0.04 to 0.08 percent. By contrast, about 0.14 to 0.25 percent of street solids are enriched with total nitrogen. A slightly higher TN enrichment factor is appropriate for catch basin and/or BMP sediments, based on the data presented in Table B-4 in Appendix B. Other researchers have also measured the nutrient enrichment associated with leaves and coarse organic matter, which is profiled in Table 11 below.

Table 10: Nutrient Enrichment of Street Solids

Solid Type	Value	% P	% N	Reference/Notes
Street Solids	Mean	0.10	0.25	CBP EP Report (2011)
Street Solids	Mean	0.05	0.20	Mean 4 Studies (Table B-2)
Street Solids	Mean	0.07	0.14	Baker et al (2014)
Street Solids, Fine	Mean	0.08	---	Sorenson (2013)
Sweeper Waste	Mean	0.04	0.15	Mean of 4 Studies (Table B-3)
Mid-Point of Data	--	**0.07**	**0.20**	Estimated

Table 11: Nutrient Enrichment of Coarse Organic Matter

Type	Value	% P	% N	Reference/Notes
Coarse Organic Matter	Mean	0.17	1.6	Baker et al 2014
Municipal Leaf Litter	Mean	0.10	0.94	Heckman and Kluchunski, 1996
Leaves	Mean	0.06	0.80	Rushton, 2006
Leaves	Mean	0.19	1.25	Ostrofsky, 1997
Leaves	Mean	0.08	0.96	Stack et al 2013
Mid-Point of Data	--	**0.12**	**1.11**	Calculated

The degree of nitrogen enrichment is about five times higher for organic matter than for street solids. On the other hand, the phosphorus enrichment of organic matter is only slightly higher than that measured for street solids. In general, these higher nutrient enrichment values are appropriate to apply to practices that focus on trapping organic matter during certain times of the year (e.g., fall leaf drop).

4.5 Trace Metals and Toxics Found in Street Solids and Sweeper Wastes

Street dirt and sweeper waste are typically contaminated by trace metals, polycyclic aromatic hydrocarbons, petroleum hydrocarbons, pesticides and other potential toxicants. For example, Table 12 summarizes the trace metal content of sweeper waste, which are roughly twice as high as those observed in urban soils.

Table 12. Trace Metal Content of Street Sweeper Waste (mg/kg)

Study	STATE	Copper	Lead	Zinc
Sorenson, 2013	MA	72	62	146
Sorenson, 2013	MA	47	111	169
SPU, 2009	WA	49	103	189
CSD, 2011a	CA	92	23	136
CSD, 2011b	CA	157	204	210
Walch, 2006	DE	64	81	208
MEAN		**80**	**97**	**176**
Urban Soils (Pouyat et al, 2007)		35	89	91

Table 13. Other Toxics Found in Street Sweeper Waste or Street Dirt (mg/kg, unless specified otherwise)

Toxic Contaminant	Sediment Concentration
Petroleum Hydrocarbons	Diesel range: 200 to 400 mg/kg Motor Oil/Oil Grease: 2,200 to 5,500 mg/kg
Polychlorinated Biphenyls (PCB's)	0.2 to 0.4 mg/kg
Polycyclic Aromatic Hydrocarbons (PAH)	Total: 2,798 ug/kg, Carcinogenic: 314 ug/kg
Pthalates	1,000 to 5,000 ug/kg
Pesticides	Pyrethroid pesticides present
Chloride	980 mg/kg
Mercury	0.13 mg/kg
Based on 3 West Coast Studies of street dirt and/or sweeper waste contamination, plus one Delaware Study	

Several west coast studies have also established that sweeper wastes are highly contaminated with petroleum hydrocarbon and polycyclic aromatic hydrocarbons (SPU, 2009, CSD, 2010). These compounds are hydrophobic and are strongly associated with the organic fractions of street solids (Bathl et al, 2012, Nowell et al 2013). Street solids are also enriched with mercury, PCBs, pthalates and pyrethoid pesticides, as well as very high chloride levels due to winter salt applications (Table 13).

Given the high level of toxic contaminants found in street solids and sweeper wastes, street cleaning may be an excellent strategy to reduce the toxic inputs from urban portions of the Chesapeake Bay watershed.

4.6 Summary Review of Recent Street Cleaning Research

The panel focused its effort on street cleaning research conducted after the 2006 literature review that was the primary resource used by the last expert panel to develop its recommendations (CWP, 2006a). About ten studies were published since 2006, and these newer papers are summarized in the ensuing section.

Overall, the new studies have produced a lot of quantitative data on the sediments and nutrients that are picked up by sweepers, but none measured a detectable change in sediment or nutrient concentrations within the storm drain system. Once again, the study designs were not robust enough to collect enough stormwater samples before and after treatment to show a statistically significant difference. Most of the recent studies relied on simulation models to predict the impact of different street cleaning scenarios on pollutant removal, although the empirical data collected during monitoring was used to calibrate or validate their models.

2005 National Literature Review: This review was conducted by the Center for Watershed Protection on behalf of the CBP Urban Stormwater Workgroup (CWP,2006a). It included more than a dozen research studies, many from the Nationwide Urban Runoff Project in the early 1980's. Most of the studies relied on older mechanical broom technology and showed street cleaning had a small impact in reducing stormwater pollutants, with a few studies showing no detectable impact. Given the differences in street types, sweeping frequency and, technology between the studies, an overall removal rate could not be calculated. Instead, CWP developed a conceptual mass balance model to derive a conservative pollutant removal rate.

Based on the model results, CWP estimated that TSS removal could range from 16 to 32%, depending on the type of sweeper technology and the intensity of the sweeping frequency. The estimated nutrient reduction attributed to sweeping was lower, and ranged between 4 to 9% for TN and TP, respectively.

Baltimore, Maryland: This monitoring study evaluated the impact of street cleaning in paired, ultra-urban catchments in the city of Baltimore (Law et al, 2008). The streets experienced high street solid loadings rates, and pre-treatment monitoring of the storm drains indicated stormwater pollutant EMCs that were about twice as high as the national average (Pitt et al, 2004). The before and after study design evaluated whether vacuum-assisted sweeping at frequent intervals (twice a week) would influence pollutant event mean concentrations during storm events. More than 50 pre- and post-treatment stormwater samples were collected over a two-year period.

Despite this effort, Law concluded that "an insufficient number of stormwater samples were collected to statistically determine the effectiveness of street sweeping in paired urban catchments". In addition, the study sampled the particle size distribution and nutrient content of street solids, and assessed the nutrient concentrations from the mass of solids removed during storm drain cleanouts. The Baltimore data on stormwater quality, street solids and catch basin sediments were all used by the last expert panel to formulate their recommended pollutant removal rate for street cleaning.

Madison, Wisconsin: This four-year, paired subwatershed study evaluated the effectiveness of weekly cleaning using three different sweeping technologies in residential streets (Selbig and Bannerman, 2007). In addition to stormwater monitoring, the team analyzed the particle size distribution and nutrient content of street solids. The study found street solid loading was highest in the early spring, a result of the remnant sand applications during the winter months. Measured street solid pick-up efficiencies ranged between 50 to 80% for the two vacuum-assisted sweeper options, but were negligible for the mechanical broom sweeper.

The study could not find a detectable impact of sweeping on stormwater EMCs for sediment or nutrients, but concluded the high variability observed in their stormwater runoff may have masked the real impact. The Wisconsin DNR has shifted to the use of stormwater models to predict the impact of different street cleaning scenario for phosphorus TMDLs. Many of the functions and parameters in their model are informed by data drawn from this study, and have been calibrated the street solid loading time series it collected.

Seattle, Washington: This study was conducted by the city of Seattle to respond to a MS4 stormwater permit condition that required them to evaluate the pollutant removal capability of their current street and storm drain cleaning programs (SPU, 2009). This study monitored street solid yield, sweeper mass yield, sweeper pick-up efficiency and catch basin accumulation in residential and industrial streets. The study evaluated the effect of regenerative air sweepers that swept city streets every other week. The study measured regenerative air sweeper street solid pick up efficiencies on the order of 50 to 90%.

The study design expressly avoided stormwater quality sampling, given the inherent variability of pollutant concentrations in the urban landscape. The authors did collect extensive data on the particle size distribution and pollutant content in street solids and sweeper wastes. The study assumed that the pollutants in street solids that are picked up by sweepers are effectively removed from downstream water bodies (i.e., 100% delivery of all street dirt particles to the storm drain), but provided no evidence to confirm this hypothesis. Based on this assumption, the authors concluded street cleaning every two weeks produced solid reductions in the range of 40 to 60%, and could also reduce toxics and metals to an unspecified degree.

By contrast, they found that frequent street cleaning did not change the solids accumulation rate in test catch basins. The study did not make any recommendations to assign a pollutant removal rate for street cleaning in local TMDLs.

San Diego, California: Like Seattle, this study was conducted in response to a MS4 permit condition, as well as to comply with trace metal TMDLs for local waterways. They looked at how effective three sweeper types were in influencing measured street solids and sweeper waste yields on residential and commercial streets, as well as arterial highways (CSD, 2010, 2011). They also measured the particle size distribution and pollutant content of street solids and sweeper waste, including a number of trace metals and toxic contaminants.

The authors concluded that street cleaning was an effective means of reducing pollutants discharged in stormwater runoff, but did not provide a lot of documentation to support their conclusion. Although there were mixed results due to street conditions, vacuum-assisted sweepers had the highest pick-up efficiency, mechanical broom sweepers the least, with regenerative air sweepers in the middle. The study also tested the effect of high intensity cleaning (every 3 to 4 days), and whether paved medians should be swept. The major difference was noted for the most intense cleaning frequency (two times/week) compared to weekly cleaning. Paved medians were found to have high rates of street solid accumulation, which made them a priority target for street cleaning.

Cambridge, Massachusetts: This USGS study measured pick up efficiency for three different street sweepers operating on multi-family and commercial streets for street solids and phosphorus (Sorenson, 2013). The study was conducted to provide management data to respond to a phosphorus TMDL for the Lower Charles River. The study design did not include sampling of pollutants in stormwater runoff, but focused on changes in street solid accumulation rates over time. Data acquired during the study were used to calibrate a WinSLAMM model of typical street conditions in the Boston area, along with other Boston area sweeping research (Smith, 2002, Zarriello, et al 2002, Breault et al, 2005).

Based on the model, Sorenson (2013) predicted sediment removal of 3 to 20%, and total phosphorus removal of 3 to 9%, over a range of sweeping frequencies from 3 times per week to once a month. Regenerative air and vacuum-assisted sweepers were found to have higher removal rates than mechanical broom sweepers.

Prior Lake, Minnesota: This study looked at the interaction of three different sweeping frequencies and adjacent tree canopy in several residential streets in the Twin Cities area (Baker et al, 2014). The study departed from earlier research in that they sampled the nutrient content of both solids and organic matter that were picked up by a regenerative air sweeper, regardless of particle size. The team observed seasonal spikes in the accumulation of solids and nutrients over the two year study period, with a peak in the fall that coincided with fall of deciduous leaves.

Although no stormwater samples were collected, the authors found higher nutrient loads were associated with the organic fraction of the sweeper waste, for all particle sizes. They also reported a strong link between the phosphorus load picked up by sweepers and the degree of adjacent tree canopy for residential streets. Based on their results, the team concluded that an increased intensity of street cleaning that coincides with the peak of fall leaf drop may be a potential strategy to reduce lake eutrophication. Further research on the effectiveness of seasonal street cleaning is now underway.

State of Florida: This study investigated the nutrient content in street sweeper wastes, catch basin debris and pond sediments from residential, commercial and highway land uses (Berretta et al, 2011). The project collected more than 450 sediment samples from across the state, which contributed to a much greater understanding of the degree of nutrient enrichment in both sweeper waste and BMP sediments.

Easton, Maryland: While this study did not look at street cleaning per se, it did evaluate the performance of a leaf net filter to capture and remove organic matter and sediments that would have been otherwise discharged to the Tred Avon River (Stack et al 2013). The net filters were located at the terminus of the storm drain system and were found to be effective in capturing organic debris. The dry-weight nutrient content of the organic matter captured in the nets was measured and found to be a significant source of N and P discharged from the outfall. Stack noted that this nutrient input would not have been detected through conventional stormwater monitoring equipment.

4.7 Key Panel Conclusions About Recent Street Cleaning Research

Based on its research review, the panel came to several conclusions about pollutant loads from roads and the effect of street cleaning in reducing them.

1. Road runoff has moderately higher nitrogen concentrations than other forms of impervious cover, and merits its own land use in the next generation of the Chesapeake Bay Watershed Model.

2. The accumulation rate, particle size distribution and pollutant content of street solids follows a relatively consistent and uniform pattern across the nation. These relationships provide a strong empirical basis for modeling how solids are transported from the street to the storm drain.

3. High level of toxic contaminants are consistently found in street solids and sweeper wastes. The panel concluded that street cleaning may be an excellent strategy to reduce the toxic inputs from urban portions of the Chesapeake Bay watershed, given the high level of toxic contaminants found in street solids and sweeper wastes.

4. The effect of street sweeping will always be modest, even when it is done frequently.

The primary reason is that storms are also efficient at cleaning the street and moving smaller particles into storm drain.

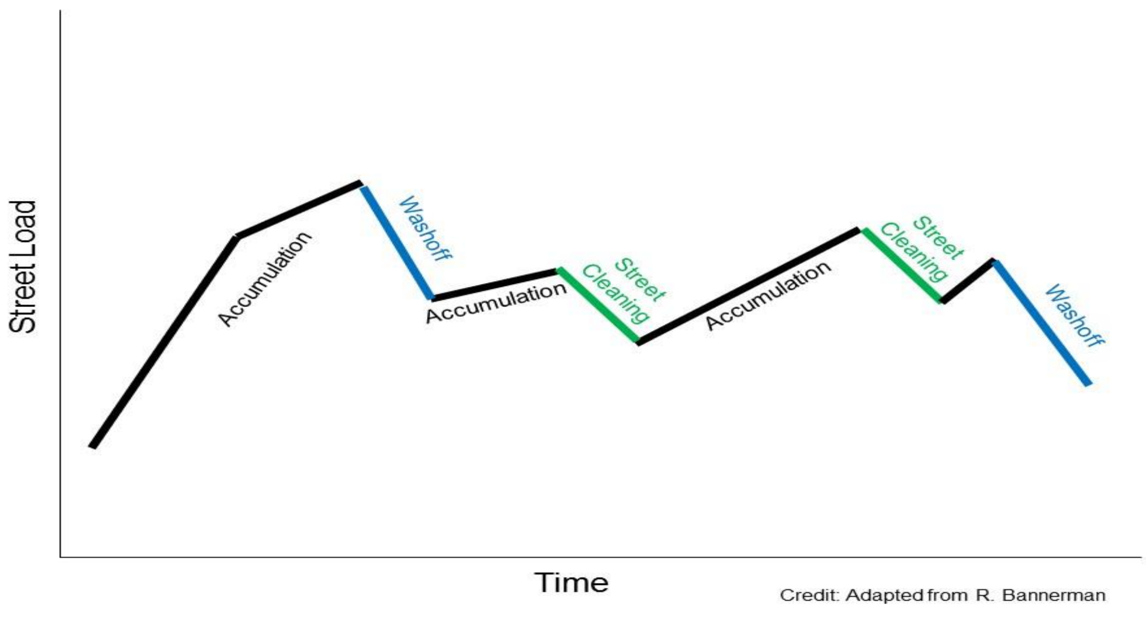


Figure 5. The Relationship Between Solids Accumulation, Street Cleaning and Wash-off During Rain Events.

On average, storm events occur every 4 to 5 days in the Bay watershed, which creates the "sawtooth" pattern in street solids shown in Figure 5. On dry days, solids build up on the street surface, only to be washed off during storm events, unless a sweeper happens to come sooner. Given that sweeping usually occurs on a fixed schedule, it is not uncommon to sweep streets that were recently "cleaned" by prior rain events.

5. Mechanical broom sweepers have little or no nutrient reduction benefit

This conclusion surprises many, particularly when they see large loads of street solids that the sweepers pick up. But researchers have concluded that while mechanical broom sweepers pick-up a lot of coarse grained particles, they have a low overall sediment pick-up efficiency and leave behind fine-grained particles on the street that are subject to future wash-off (CWP,2006a, Selbig and Bannerman, 2007, CSD, 2010, and Sorenson, 2013). The panel does note that mechanical sweepers may have some capability to remove gross solids, trash, litter and some toxic contaminants.

Figure 6 shows the sediment pick-up efficiency for three kinds of sweepers as a function of particle size on the street. Street sweepers tend to be effective at picking up coarse-grained particles, but actually increase the amount of fine particles on the street after they pass.

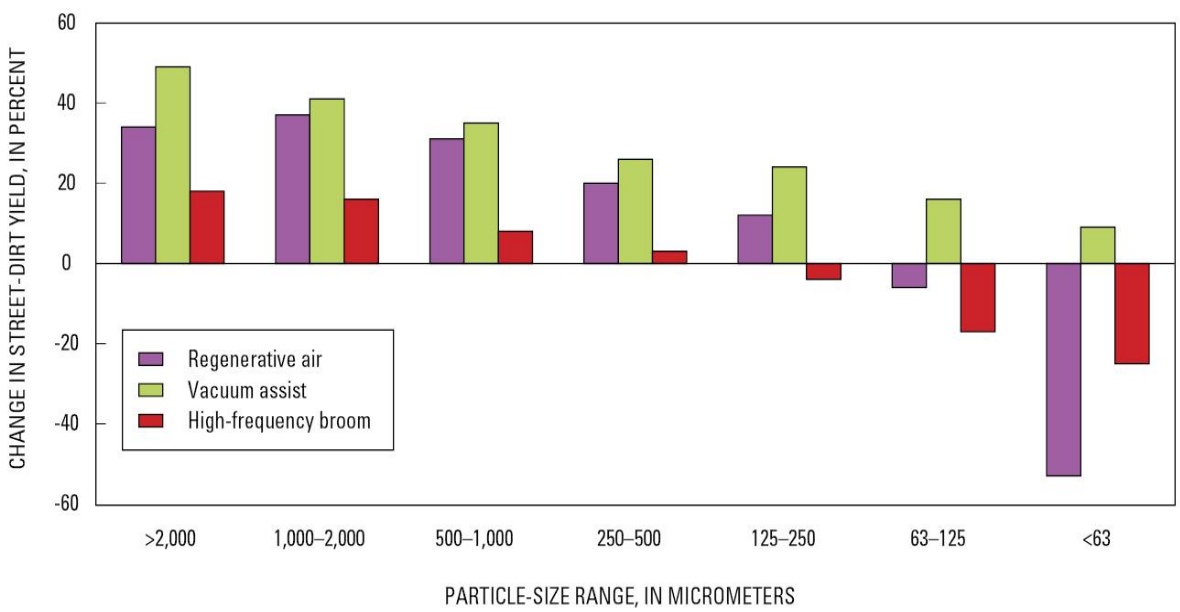


Figure 6 Comparative pick up efficiency of three types of sweepers (Selbig and Bannerman, 2007).

The mechanical broom actually dislodges fine particles that were trapped in the nooks and crannies of the street surface, making them available for future wash-off. Consequently, mechanical sweepers have very limited capability to reduce sediment concentrations discharged to the storm drain system. This finding is illustrated in Figure 7 which shows the weekly average sediment loading for two streets --one swept by a mechanical broom sweeper versus a control street that was not swept at all. There was no statistical difference between the two street treatments, suggesting that the broom sweeper was largely ineffective.

In addition, the panel could find no other credible monitoring or modeling studies that showed mechanical broom sweepers could reduce sediment loads by more than 10%, even at the most frequent sweeping intervals. Several studies indicated that broom sweeper had a zero or negative efficiency (Selbig and Bannerman, 2007, Sorenson, 2013, Waschbush, 1999).

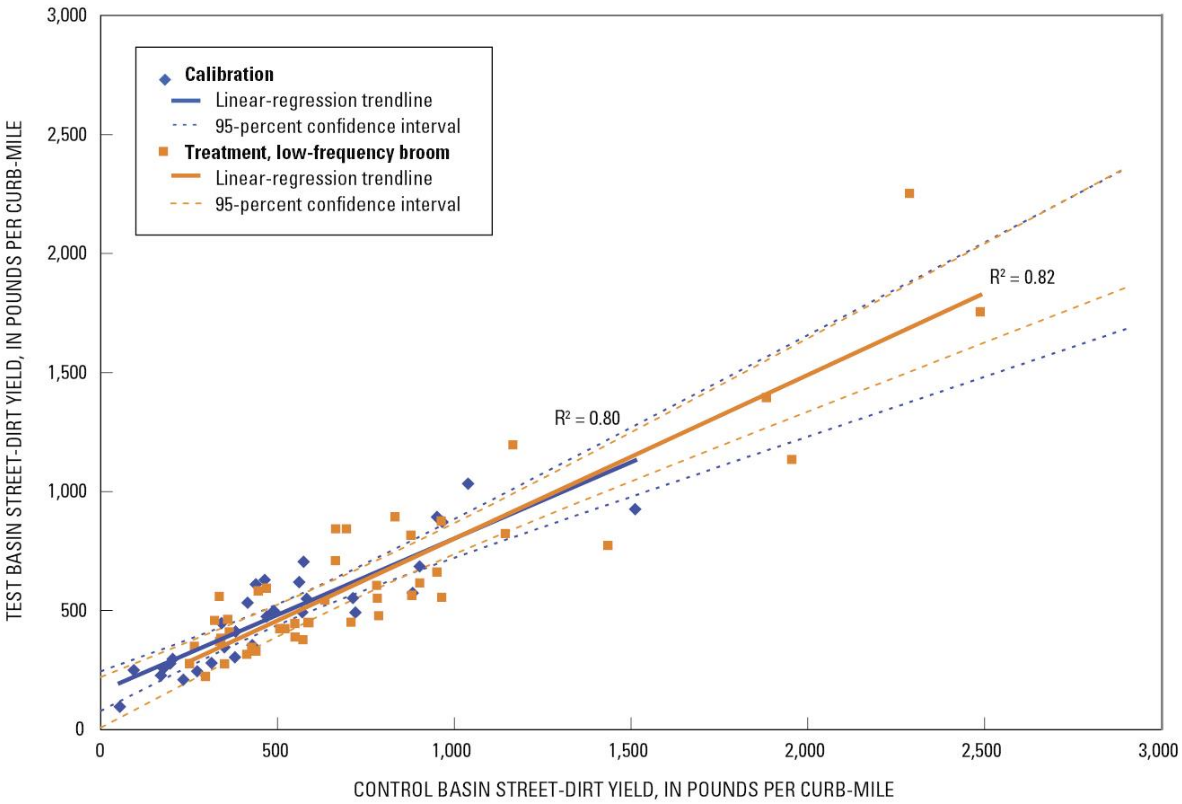


Figure 7. Response in weekly average street dirt load for control street (un-swept) and a street cleaned with mechanical broom sweeper in Madison, WI (Source: Selbig and Bannerman, 2007).

6. Other street cleaning technologies show much higher sediment reduction potential.

Two other street cleaning technologies show much more promise in picking up solids from the street surface -- regenerative air sweepers and vacuum assisted sweepers. Research has consistently shown that these technologies have pickup efficiencies in the 50 to 90% range, and most importantly, have the capability to pick up all particle size fractions from the street surface (Selbig and Bannerman, 2007, Law et al 2008, SPU, 2009, CSD, 2010 and 2011, and Sorenson, 2013).

An example of the high pick-up efficiency achieved by these sweeper technologies is provided in Figure 8 which shows how a regenerative air sweeper was able to sharply reduce weekly street dirt loads, compared to a control street that was not swept (note the sharp contrast with Figure 7).

The panel noted that high street dirt pick-up efficiency does not automatically equate to downstream reductions in sediment loads, since many of the coarse-grained sediments may never reach the storm drain inlet, or if so, may be re-deposited in the urban stream corridor.

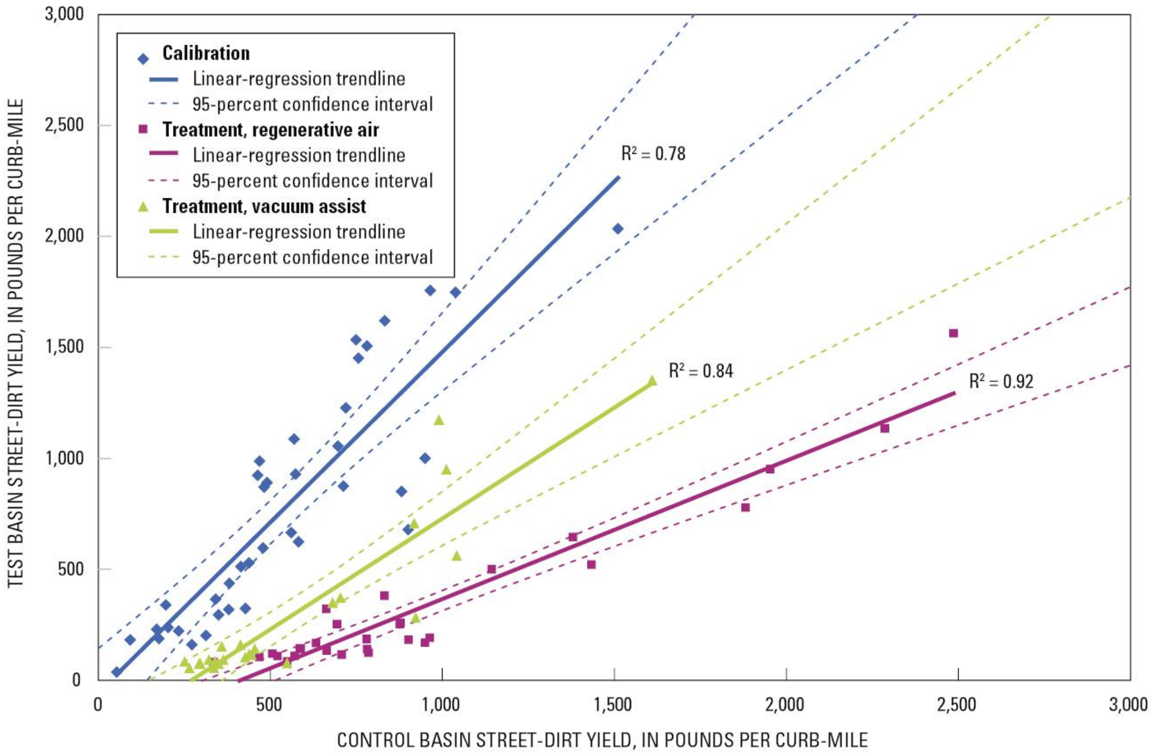


Figure 8 Comparison of Street Dirt Load for Control Street and Street Swept by Regenerative Air Sweeper (Selbig and Bannerman, 2007)

The panel could not find enough monitoring data to make a distinction between the two advanced street cleaning technologies -- regenerative air and vacuum assisted sweepers -- when it comes to sediment pick-up efficiency. Therefore, the panel lumped the two technologies together during the WinSLAMM model analysis.

7. Street parking and other operator factors can sharply diminish sweeper pick-up efficiency.

Sweeping practitioners frequently note that real world factors such as the number of parked vehicles along a street can sharply reduce pick-up efficiency (Pitt, 1979). The main reason is that parked cars limit sweeper access to the curb and gutter where many of the particles are located. Pitt has developed relationships to quantify how parking reduces sweeper pick-up efficiency (Appendix B in Tetra Tech, Inc, 2015) which have been subsequently incorporated into the street cleaning module of the WinSLAMM model.

Other practitioners have noted that pickup efficiency can be influenced by the human factor -- the skill of sweeper operators (e.g., how close they get to the curb, how quickly they can avoid cars and the speed at which they operate the sweeper --Brinkman and Tobin, 2001 and CWP, 2006a). Experienced operators also know which portions of the routes they sweep are the dirtiest and require extra attention. The panel acknowledges the importance of the human factor, but could find little direct monitoring evidence on the topic. The single study that monitored the influence of sweeper speed found that sweepers operated at 3 to 6 mph had the same street dirt yield as those operated at 6 to 12 mph (CSD, 2011).

8. The adjacent tree canopy influences the organic and nutrient loads on the street on a seasonal basis, but the management implications for this phenomenon are unclear.

As noted in Section 4.3, a significant fraction of street dirt consists of organic matter, much of which is derived from fall leaf drop, green fall and pollen deposition. Several recent studies indicate that adjacent tree canopy may exert a strong seasonal influence on TP and TN loads in the street (Baker et al 2014, Ray, 1997, Kalinosky, 2013).

A good example of the influence of tree canopy on nitrogen recovery in sweeper waste is shown in Figure 9. This Minnesota study found the highest N recovery in the late fall, with a second and smaller peak occurring in the late spring (Kalinosky, 2013). Figure 10 shows a similar pattern between tree canopy and phosphorus recovery in stormwater runoff (Selbig, 2014).

The potential nutrient loading from tree canopy is not fully known. Using data provided by Nowak (2014), the average nutrient load associated with leaf drop in the City of Baltimore was estimated to be 28.8 lbs/ac/yr and 2.95 lbs/ac/yr of N and P, respectively. The unresolved issue at this time, however, is how much of the leaf drop actually gets to the curb, moves to the storm drain and ultimately reaches the stream corridor.

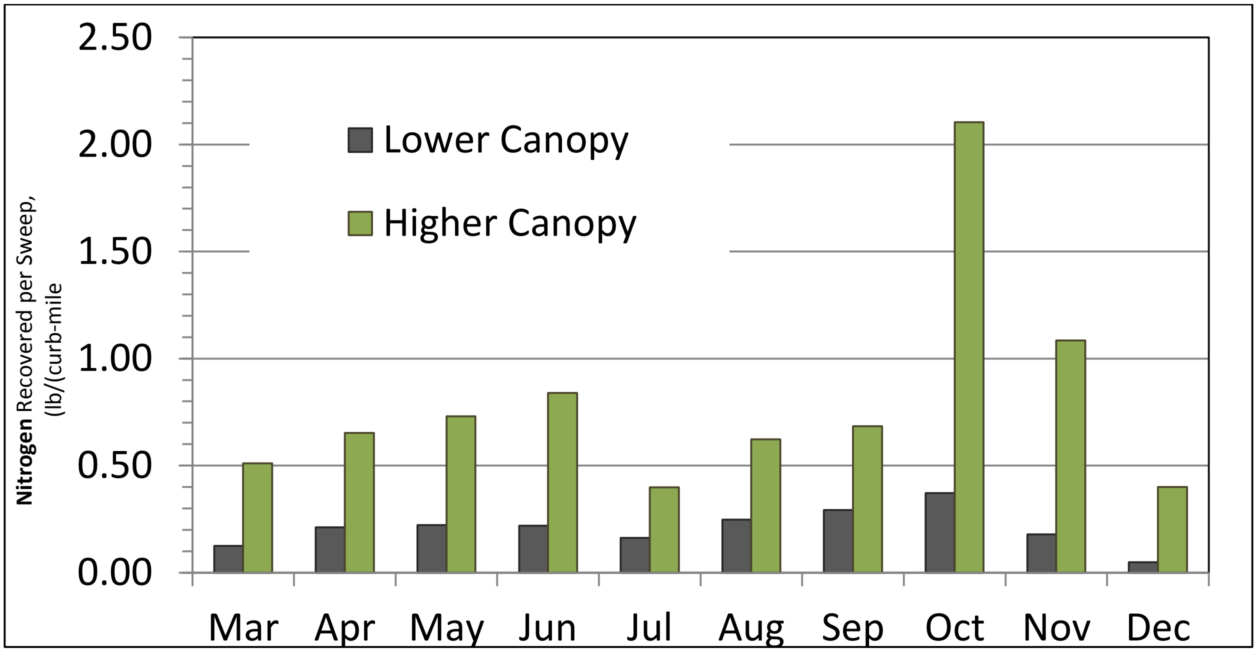


Figure 9: Effect of Street Tree Canopy on N Levels in Sweeper Waste (Kalinosky, 2014)

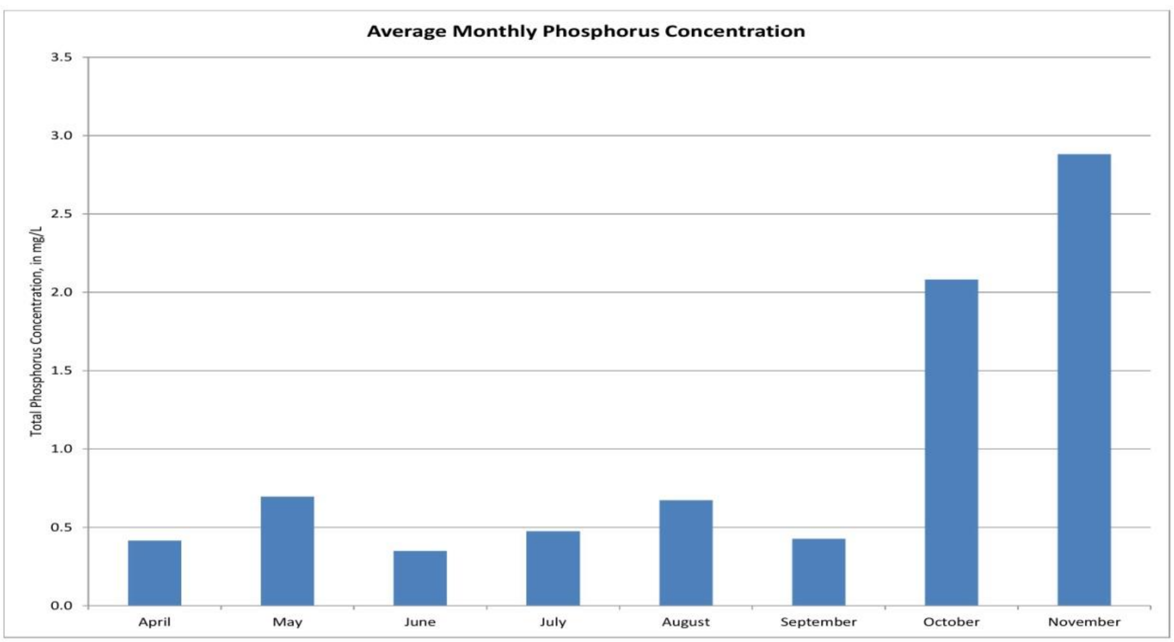


Figure 10. Seasonal changes in average monthly total phosphorus concentration measured from four residential basins in Madison, WI (USGS Wisconsin Water Science Center, unpublished data).

The panel concluded that our understanding of the fate, transport and processing of leaf litter in urban watersheds is still emerging, and there was not enough data to quantify its significance as a nutrient source at this time. In addition, the panel could find no solid data as to whether more intensive street cleaning designed to coincide with fall leaf drop would have a definitive water quality impact.

The panel agreed that further research on this urban nutrient management strategy should be a top priority, since the findings are expected to have a major influence on the next generation of street cleaning programs. A CBP Scientific and Technical Advisory (STAC) research synthesis report on the sources of urban nutrients arrived at a similar conclusion about the potential importance of leaf drop (Sample et al, 2015).

9. No monitoring studies have shown a detectable water quality change within storm drains that can be attributed to upland street sweeping, and it is doubtful whether future monitoring efforts will be any more successful. Given the limitations of monitoring, the panel concurred that empirically-based simulation models were needed to derive street cleaning estimates.

There are several reasons why it has been so difficult to quantify the impact of street cleaning through stormwater monitoring. To start, the presumed effect of street cleaning is expected to be rather low given the "sawtooth" pattern in how solids build up and wash-off street surfaces (Figure 5). Such small differences are hard to detect given the variability in stormwater runoff from streets and roads (as well as the variability in street conditions and types across a community).

The variability in sediment and nutrient concentrations measured on both swept and un-swept streets is enormous (Figure 11).

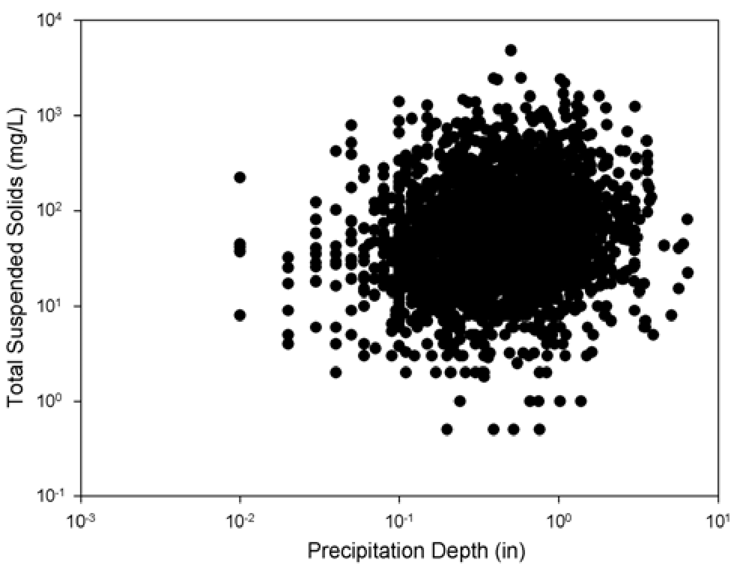


Figure 11 Example of the Variability of TSS Event Mean Concentration in Urban Stormwater Runoff (Source: Pitt et al, 2004)

Figure 11 provides an indication of this variability, which shows how sediment concentrations vary as a function of rainfall depth on a logarithmic scale during more than 3,500 runoff events sampled as part of the National Stormwater Quality Database (Pitt et al, 2004). The coefficient of variation (COV) associated with the pollutant concentrations in stormwater runoff samples range from 1.0 to 1.8 (Table 14). A higher COV indicates higher variability, which means a greater number of samples are needed to detect a significant difference.

Table 14. Samples Required to Detect Change Given EMC Variability

Pollutant	Coefficient of Variation [1]	Approx. No. of Samples Required [2]
TSS	1.8	250
TN	1.0	75
TP	1.3	150

[1] Per most recent edition of National Stormwater Quality Database (Pitt, 2014)
[2] 95% confidence interval and assuming a sampling error rate of 25%, as shown in Figure 2 of Sample et al (2012).

The practical monitoring implication is that a very large sample size is required to overcome the variability and establish a significant difference between treatments. As shown in Table 14, hundreds of paired samples must be collected to detect a significant difference within an individual catchment (if it exists), which is beyond the scope of most research budgets.

The difficulty in getting enough stormwater samples has been cited as a major problem by many sweeping researchers in the past (Selbig and Bannerman, 2007, Law et al, 2008 and SPU, 2009), and most new research efforts have shifted to alternate street solid monitoring methods, or employ hydrologic simulation models.

The panel agreed that modeling was the only approach to derive reliable sediment and nutrient reduction rates associated with street cleaning. The advantage of a modeling approach is that it allows managers to determine removal rates for hundreds of different street cleaning scenarios that could never be definitively established by a monitoring program (e.g., parking conditions, street types, sweeping frequencies, etc.).

While a modeling approach helps managers make more informed decisions, the panel cautions that users should also be aware of the inherent limitations and uncertainty involved in any model predictions.

Section 5: WinSLAMM Modeling Analysis

The Panel selected the Source Loading And Management Model for Windows (WinSLAMM) as the best tool to estimate sediment removal rates associated with different street cleaning scenarios in urban watersheds of the Chesapeake Bay (Version 10.1.0, P&V Associates 2014; Pitt and Voorhees 2000) WinSLAMM is widely accepted and documented model that simulates urban hydrology, pollutants and the effect of stormwater practices.

WinSLAMM is an event-based model that calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different source areas (e.g., roofs, streets, parking areas, landscaped areas and undeveloped areas). The basic street cleaning module in WinSLAMM conservatively simulates sediment reductions associated with different street cleaning scenarios, and relies on sediment production and wash-off functions derived from empirical monitoring data. At this point in time, the model does not have the capability to explicitly simulate the effect of leaf drop on street solid dynamics.

The expert panel concurred that the existing street cleaning control module in WinSLAMM was a robust tool to evaluate a wide range of street cleaning scenarios. The model has been used to evaluate the water quality impact of street cleaning in earlier studies (Pitt et al, 2004, Sorenson, 2013), and has been accepted by regulators in at least two states as a tool to determine TP reduction credits for lake TMDLs (WI and MA). Figure 12 shows a screen shot of the user interface for the street cleaning module.

5.1 Customizing WinSLAMM for Chesapeake Bay Street Sweeping

Under the technical direction of the expert panel, Tetra Tech developed a Chesapeake Bay application of the WinSLAMM model to estimate the effect of street cleaning under a wide range of scenarios. The panel and Tetra Tech worked together over nine months in 2014 to conduct the modeling analysis, and document the assumptions used and scenarios evaluated. The two products of this effort were a technical memo summarizing the street cleaning scenarios that were evaluated (Tetra Tech, 2015), and a spreadsheet developed to allow users to calculate their own sediment reductions. Copies of both products are available on the Chesapeake Stormwater Network website (www.chesapeakestormwater.net)

The street cleaning module was calibrated and verified to real street dirt datasets. The Bay application of the model was customized to incorporate east coast sediment buildup and wash-off functions, Chesapeake Bay rainfall data, and a representative range of street types, sweeper technologies and parking conditions (Table 15). Once the panel approved the model, it was then used to assess different scenarios involving different combinations of sweeping technology, frequency, parking density and controls at four different street types that were used as a baseline.

The Panel elected to not to use WinSLAMM to explicitly simulate nutrients, and instead estimated them based on empirical nutrient enrichment for street solids and sweeper waste that were derived in Section 4.4 of this report.

<table>
<tr><td colspan="2">Table 15. Adapting the WINSLAMM Model for the Chesapeake Bay Watershed</td></tr>
<tr><td colspan="2">Bay rainfall data. The model used the calibration period from 1995 through 2005 using Washington National Airport Station event-based rainfall data. The rainfall data was processed assuming the minimum number of hours between events is 6 hours and the minimum rainfall event depth is 0.01 inch.</td></tr>
<tr><td colspan="2">East Coast input data files were prepared to represent 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</td></tr>
<tr><td colspan="2">Four different street types were simulated to represent in different land uses that had curb and gutter drainage systems:

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.

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.

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.

Arterial highway: A four-lane divided road with median with barrier; high-speed traffic with turn lanes; and no on-street parking. Assumed to be commercial land use</td></tr>
<tr><td colspan="2">Three different sweeping start/stop dates to reflect regional differences in climate across the watershed:
Sweeping occurs over the entire year
Sweeping suspended December 1, restarts March 15
Sweeping suspended December 15, restarts February 15</td></tr>
<tr><td colspan="2">Six different fixed sweeping schedules</td></tr>
<tr><td>2PW = 2 passes per week
1PW = 1 pass every week
1P2W = 1 pass every 2 weeks</td><td>1P4W = 1 pass every 4 weeks
1P8W = 1 pass every 8 weeks
1P12W = 1 pass every 12 weeks</td></tr>
<tr><td colspan="2">Four seasonal sweeping schedules (more intensive in Spring or Fall)</td></tr>
<tr><td colspan="2">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</td></tr>
<tr><td colspan="2">Two Levels of Sweeper Technology</td></tr>
<tr><td>MBC = Mechanical broom cleaning</td><td>VAC = Vacuum assisted cleaning</td></tr>
<tr><td colspan="2">Four Options for Street Parking Density and No Parking Enforcement</td></tr>
<tr><td colspan="2">For more details, consult the technical memo (Tetra Tech, Inc., 2015)</td></tr>
</table>

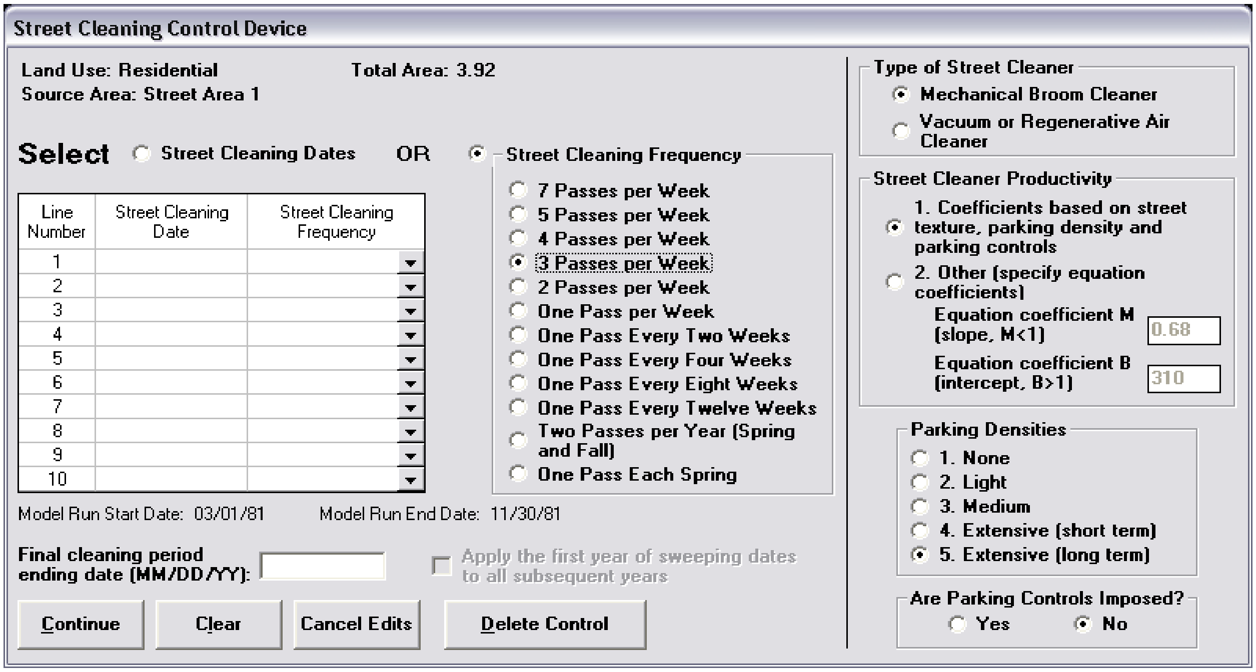


Figure 12. Screen Shot of WinSLAMM User Interface (P&V Associates, 2014)

Section 5.2 Key Findings from the WinSLAMM Modeling.

The detailed findings on sediment reductions for different street cleaning scenarios can be found in Tetra Tech (2015) and they generally mirror the basic findings that emerged from prior monitoring studies. Some of the general findings are described below.

- While nearly a thousand street cleaning scenarios were evaluated, only half of them produced significant sediment reductions (i.e., > 5% of annual sediment load reduced).

- The model predicted very low sediment reductions for nearly every mechanical broom cleaning scenario analyzed (see panels B and D in Table 16). Mechanical broom sweepers still comprise much of the local sweeper fleet in the Bay watershed.

- By contrast, vacuum assisted and regenerative air sweepers were estimated to reduce sediment by 5 to 45%, with higher reductions associated with more intensive sweeping regimes. The relationship between sweeping frequency and sediment reduction for advanced sweeper technologies is illustrated in Figure 13. The estimated sediment reduction is very modest for weekly and quarterly sweeping, but begins to climb sharply when bi-weekly or even more frequent sweeping is conducted.

- Figure 13 also indicates that sediment reduction is influenced by the type of road that is swept. Arterial, ultra-urban and residential streets had higher sediment reduction rates than commercial streets. The effect of street type on sediment reduction, however, was masked by the effect of on-street parking (Panel C in Table 16). As can be seen, high levels of on-street parking sharply decrease street-cleaning efficiency.

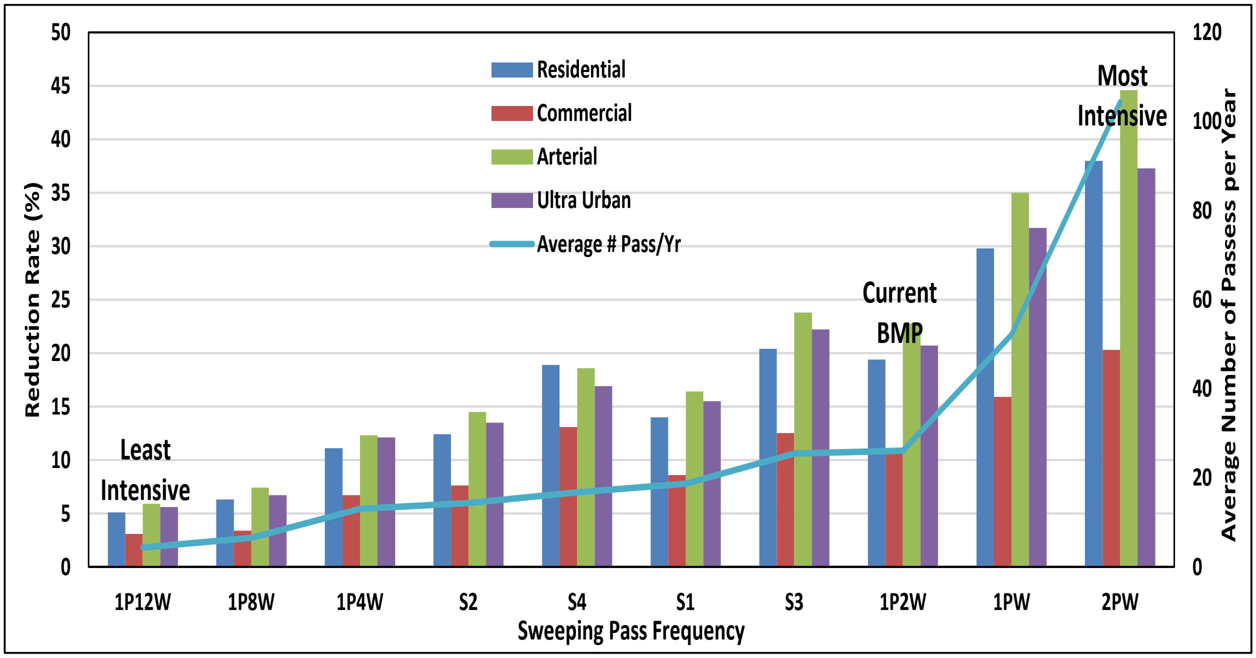


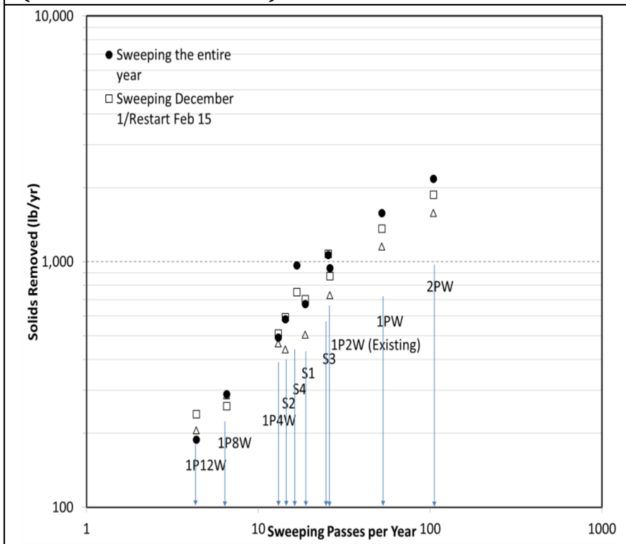
Figure 13. Effect of Sweeping Frequency and Street Type on Sediment Removal, Achieved by a Vacuum Assisted Sweeper (Tetra Tech, Inc, 2015)

- The optimal seasonal cleaning scenario was S3 (one pass every week from March to April and October to November, and monthly sweeping the rest of the year).

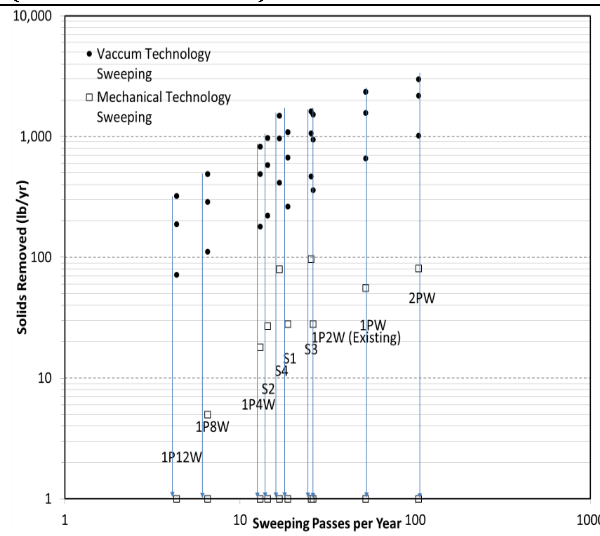
- The other seasonal impact involves the length of the winter shut down period, which varies from the top and the bottom of the watershed. Sweeping is not feasible during snowy or extremely cold weather, since sweeper water lines freeze, street surfaces are covered by ice and snow and operators are re-assigned to drive snow plows. The effect of winter sweeping shutdown was very modest, compared to areas of the watershed where sweeping is done year round (Panel A in Table 16).

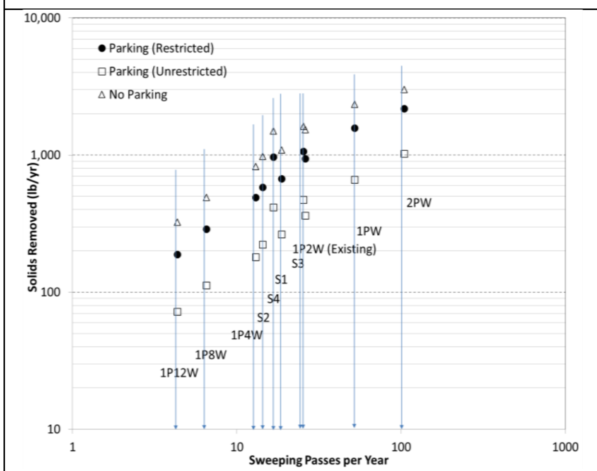
Table 16.
WINSLAMM Sediment Output for Different Street Cleaning Scenarios
(Tetra Tech, 2015)

Panel A: Effect of Winter Shut Down (residential street)

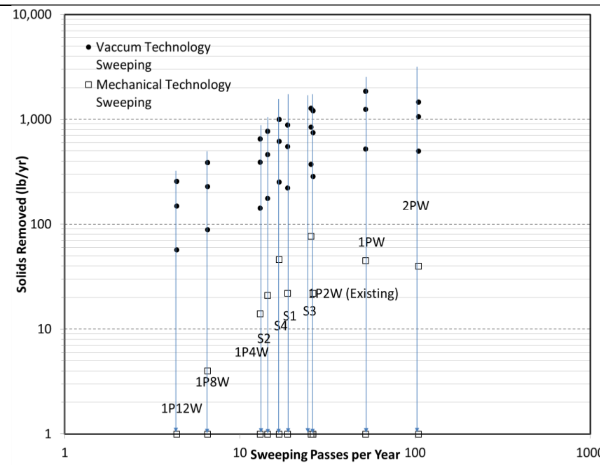


Panel B: Effect of Sweeper Technology (residential street)





Panel C
Effect of Parking Controls (Residential Street)



Panel D
Effect of Sweeper Technology (Ultra-urban)

Section 6:Recommended Credits for Street and Storm Drain Cleaning

Section 6.1 Derivation of the Street Cleaning Credit

The panel used the model output from the Chesapeake Bay version of WinSLAMM to develop its protocol for calculating sediment and nutrient reductions associated with different street cleaning scenarios. The model was used to simulate the expected annual sediment reduction for 960 different street cleaning scenarios, which included 3 different lengths for winter shutdown, 4 types of streets, 2 sweeper technologies, 10 different cleaning frequencies, and 4 combinations of street parking conditions and controls. A spreadsheet was created to store the estimated percent sediment removal for each street cleaning scenario using a standard sweeping unit of curb-miles swept

The spreadsheet tool was then used to define percent nutrient removal rates by applying a nutrient enrichment ratio (Table 18) to the mass of sediments removed per acre in each street cleaning scenario, and subtracting the resulting nutrient load from the unit area nutrient load for impervious cover calculated by the watershed model.

The standard street cleaning unit are curb miles swept. In general, one impervious acre is equivalent to one curb-lane mile swept, assuming they are swept on one-side only. The only qualifying condition for the street cleaning practice is that the streets must have curb and gutters.

The panel elected to consolidate the model results to show specific removal rates for eleven different street cleaning practices, primarily involving the use of advanced street cleaning technology at different frequencies (Table 17).

Table 17. Pollutant Reductions Associated with Different Street Cleaning Practices

Practice #	Description [1]	Approx Passes/Yr [2]	TSS Removal (%)	TN Removal (%)	TP Removal (%)
SCP-1	AST- 2 PW	~100	21	4	10
SCP-2	AST- 1 PW	~50	16	3	8
SCP-3	AST- 1 P2W	~25	11	2	5
SCP-4	AST- 1 P4W	~10	6	1	3
SCP-5	AST- 1 P8W	~6	4	0.7	2
SCP-6	AST- 1 P12W	~4	2	0	1
SCP-7	AST- S1 or S2	~15	7	1	4
SCP-8	AST- S3 or S4	~20	10	2	5
SCP-9	MBT- 2PW	~100	1.0	0	0
SCP-10	MBT- 1 PW	~50	0.5	0	0
SCP-11	MBT- 1 P4W	~10	0.1	0	0

AST: Advanced Sweeping Technology MBT: Mechanical Broom Technology

[1] See Table 15 for the codes used to define street cleaning frequency

[2] Depending on the length of the winter shutdown, the number of passes/yr may be 10 to 15% lower than shown

The rationale for consolidating the 960 street cleaning scenarios into 11 generic street cleaning practices was as follows. First, 65% of the street cleaning scenarios that were simulated showed no pollutant reduction benefit, and therefore could be ignored. Second, fewer BMP options helps reduce the reporting burden for local and state agencies, and makes it easier to incorporate them within Scenario Builder (i.e., the tool used to enter BMPs into the CBWM).

Third, the main determinant of sediment removal rate was advanced sweeping technology and cleaning frequency. While the WinSLAMM model was sensitive to other factors (e.g., street type, parking density, parking restrictions, and length of the winter shutdown period), it would be hard to map or verify them over the entire Chesapeake Bay watershed. In addition, while the model is a useful optimization tool, the panel did not want to oversell the accuracy, precision and reliability of its predicted sediment reduction rates.

Table 18. Default Nutrient Enrichment Factor Applied in Spreadsheet *

Enrichment Factor	% P	% N	Notes
Urban Street Solids	**0.07**	**0.20**	See Table 10 for Derivation

* Multiply the mass of sediment removed from the spreadsheet in pounds by a factor of 0.0007 and 0.0020, for TP and TN, respectively.

The street cleaning credit is an annual practice, so communities must report the number of curb miles swept for each of their qualifying street cleaning practices every year.

Communities that want to compute the pollutant reduction associated with their local street cleaning program can come up with some quick estimates based on lane miles that are swept by each SCP.

Table 19 Example of Estimating Pollutant Reduction by a Local Street Cleaning Program

Lane Miles/ Acres	SCP	Removal Rate (%) [1]			Mass Removed (lbs) [2]		
		TSS	TN	TP	TSS	TN	TP
150	SCP-2	16	3	8	31,200	69.8	14.5
50	SCP-7	7	1	4	4,550	7.8	3.8
25	SCP-4	6	1	4	1,950	3.8	1.9
75	SCP-9	1	0	0	9.75	0	0
Total for Community					37,710	81.4	20.2

[1] From Table 17, and assume one curb mile equals an acre
[2] Assume annual load from impervious cover of 1,300 lbs/ac/year (sediment), 15.5 lbs/ac/yr (nitrogen) and 1.93 lbs/ac/yr (phosphorus) --Table 4

Table 19 shows the estimated reductions in a community that relies mostly on advanced street cleaning technology at different frequencies across its 300 mile road network each year.

By contrast, if same road network was swept by a fleet of older mechanical broom sweepers, the sediment and nutrient reduction credits would be trivial. For this reason, communities are encouraged to use the spreadsheet for planning purposes in order to optimize which combination of street cleaning scenarios can maximize pollutant reduction within their jurisdiction at the least cost.

6.2 Note on Interaction of Street Cleaning and Other BMPs

A key modeling issue involves how street cleaning interacts with other BMPs located within the same catchment. Roads inevitably intersect drainage areas that may (or may not) be served by upstream and/or downstream BMPs. A potential double counting situation is created when street cleaning interacts with other BMPs in the same catchment. The panel could not find a practical method to isolate the BMP interaction effect over the entire road network of a MS4, and certainly not at the scale of the Chesapeake Bay watershed. The panel concluded that there was a small possibility for double counting, but given its conservative protocol, made it too small to quantify.

6.3 Phase out of the Existing Methods to Calculate Street Cleaning Credit

The panel agreed that the two existing methods for calculating pollutant reduction for street cleaning by the 2011 panel should be phased out in the following manner:

- The existing "qualifying lane miles method" should be replaced by the more versatile credit proposed by this expert panel as soon as possible. The WinSLAMM modeling used to define the new credit is more technically defensible and provides municipalities with a greater range of street cleaning scenarios in which they can earn credit, assuming they use advanced sweeper technology.

- The existing "mass loading method" may continue to be used until 2017, but should be completely phased out when the Phase 6 CBWM model becomes operational (2018).

- Until the new street cleaning credit is fully adopted, the panel encourages states to require that locals use only <u>one</u> of the existing methods to report the credit. The panel felt that it was not wise to provide two methods that may give different answers to the same question. It also eliminates the possibility of users "shopping" for the method that gives them the most credit.

6.4 Storm Drain Cleaning Credit

The panel recommended a credit for sediment and nutrient reduction for solids that are directly removed from catch basins, within storm drain pipes or captured at the storm drain outfall. The credit promotes innovative practices such as net filters, gross solids controls, and end of pipe treatment (Figure 14), as well as traditional catch basin cleanouts.

The credit is computed in three steps:

> **Step 1:** Measure the mass of solids/organic matter that is effectively captured and properly disposed by the storm drain cleaning practice on an annual basis.
>
> **Step 2:** Convert the initial wet mass captured into dry weight. The following default factors can be used to convert wet mass to dry weight in the absence of local data. The conversion factors are 0.7 for wet sediments (CSN, 2011) and 0.2 for wet organic matter (Stack et al, 2013).
>
> **Step 3:** Multiply the dry weight mass by a default nutrient enrichment factor depending on whether the material captured is sediment or organic in nature (see Table 20). Note: locals may substitute their own enrichment factor if they sample the nutrient and carbon content of the materials they physically remove from the storm drain.

The aggregate load collected over the course of the year, expressed as pounds of sediment and nutrients, is reported for credit.

The panel also established three qualifying conditions to ensure that the storm drain cleaning efforts have a strong water quality focus:

(1) To maximize reduction, efforts should be targeted to focus on catch basins trapping the greatest organic matter loads, streets with the greatest overhead tree canopy and/or outfalls with highest sediment or debris loads.

(2) The loads must be tracked and verified using a field protocol to measure the mass or volume of solids collected within the storm drain system. The locality must demonstrate that they have instituted a standard operating procedure (SOP) to keep track of the sediments and/or organic matter that are effectively removed. Appendix F provides an example of an SOP used to track storm drain inlet cleaning in Baltimore County, MD that may serve as a useful template.

(3) Material must be properly disposed so that it cannot migrate back through the watershed.

Table 20. Mean Nutrient Enrichment Factor to Apply to Dry Weight Mass of Solids Physically Removed From Storm Drains			
Nutrient Enrichment Factor *	% P	% N	Notes
BMP and Catch Basin Sediments	**0.06**	**0.27**	See Table B-4
Organic Matter/Leaf Litter	**0.12**	**1.11**	See Table 11
* Multiply the mass of sediment removed from the storm drain (in pounds by a factor of 0.006 and 0.027, for TP and TN, respectively.			

Figure 14: Capture of Organic Matter at the End of Storm Drain System

Photo Credits: Stack et al 2013

Photo Credits: MWCOG 2009

Section 7: Accountability for Street Cleaning Practices

7.1 General Issues on Practice Reporting and Verification

One of the deficiencies of the previous expert panel report was that it lacked detail on how the street cleaning practice would be reported, tracked and verified, so the current panel paid close attention to this issue. The panel relied on the general principles for verification of urban practices established by the Urban Stormwater Workgroup (USWG, 2014) and approved by the CBP partnership as a whole.

The Panel noted that there were some unique verification issues associated with street cleaning practices. Operational practices such as street cleaning can be variable, given that the level of sweeping effort may change from year to year due to budget resources, the size, age and technology of the local sweeper fleet, weather conditions and other factors. For this reason, street cleaning should always be reported as an annual practice, as the actual curb lane miles swept may be different every year.

7.2 Reporting, Tracking and Verifying the Street Cleaning Credit

Reporting - The panel recommended that governments only submit the total qualifying lane miles swept in the community each year that correspond to the appropriate SCP category shown in Table 17. In most cases, governments will submit additional documentation of their actual street cleaning effort to the state stormwater agency in their annual MS4 report.

Unlike other structural BMPs that require a specific geographic address (e.g., latitude and longitude), it is not really practical or useful to report a NEIEN address for the entire network of routes subject to local street cleaning. The BMP verification guidance approved by the USWG (2014) specifically allows states and localities to simplify reporting in these situations. For example, communities can simply provide the coordinates for either the centroid of (a) the jurisdiction or (b) the route in which the street cleaning occurs so that it can be assigned to the right jurisdiction within the appropriate river-basin segment. Alternatively, localities may also report the 12 digit HUC code for the watershed in which the street cleaning occurred.

Tracking and Record-Keeping - Under this approach, governments will keep accurate records to substantiate their actual street cleaning operations (including routes and mileage) so that their cleaning effort can be tracked and verified by the state MS4 regulatory agency, where necessary.

Record-keeping requirements, however, should not be so onerous that localities spend more time on paperwork than cleaning their streets. The recommended documentation may include:

1. Actual sweeper routes (and type of road)
2. Total curb miles swept on each route
3. Average parking conditions and controls along the route (optional)
4. Sweeper technology used (AST or MBT)
5. Number of sweeping passes per year on each qualifying route

In addition, the locality should maintain records of the actual miles swept, by date, for entire the MS4 sweeper fleet, over the reporting year.

Verification-The panel recommended an annual verification protocol to document local street cleaning efforts over time and provide quantitative data on sweeper waste characteristics. The proposed verification protocol entails collecting one high quality street sweeper waste sample on one route for each unique SCP they report for credit every year. The single sample is used to characterize the mass and quality of sweeper waste picked up along a single route by a single sweeper that is disposed at a landfill or a solid waste transfer station (and is not mixed with any other waste source).

For the annual sample, the MS4 should measure or estimate the following parameters:

- the volume of sweeper waste collected in the hopper, truck or dumpster (in cubic feet)
- the total wet mass of the sweeper waste (measured)
- the number of curb-miles swept over the entire route
- sweeper conditions (i.e., date swept, weather, days since antecedent rainfall, street type, parking conditions and any other operational notes)

A sub-sample of the overall sweeper waste sample should be collected and sent to a laboratory to measure the:

- actual dry weight of the wet sweeper waste
- particle size distribution of the sweeper waste
- average carbon, nitrogen and phosphorus content of the sweeper waste

Based on these measurements, the reporting agency can compute the:

- Average dry weight solids load collected over the route (lbs/curb mile)
- Wet mass to dry weight conversion factor
- Sweeper waste nutrient enrichment ratios

The locality would submit this data in their annual MS4 report so that it can be shared with other communities to provide better data to support the street cleaning practice across the Chesapeake Bay watershed.

7.3 Reporting, Tracking and Verifying the Storm Drain Cleaning Credit

Reporting - Reporting the annual storm drain credit is very straight forward. The local government simply submits the annual TSS, TP and TN load removed by the practice(s) each year (in pounds), and the coordinates of the centroid of either (a) the jurisdiction or (b) the 12 digit HUC watershed in which the cleaning occurs. This is necessary to assign the pollutant reduction credit to the proper river basin segment.

Tracking- Local governments will need to institute a tracking system and maintain records to substantiate how they calculate their annual sediment and nutrient reductions. It is strongly recommended that they develop a standard operating procedure that clearly defines:

- How the mass or volume of sediments and/or organic matter are measured in the field or at the final point of disposal
- Independent supporting documentation for storm drain cleaning effort (e.g., dumpster loads, disposal tickets, tipping fees, or vactor truck loads)
- The equation(s) used to convert wet sediment volumes to dry sediment mass, including any default values
- The nutrient enrichment ratios that are applied to the sediment mass
- The spreadsheets used to make the final computations of storm drain cleaning activity, as outlined in section 6.4 of this report.

The SOP should also contain quality assurance/quality control (QA/QC) procedures (i.e., who enters the data, who checks it and who signs off on its accuracy).

The locality will need to maintain these records over time to ensure they are properly calculating the pollutant reductions. An excellent example of a SOP used to track storm drain cleaning activity has been developed by Baltimore County, MD, and is provided in Appendix F of this report.

Verification-- The process for verifying the storm drain cleaning practice is similar to that used to verify the street cleaning practice. Once a year, a composite sample is collected from the storm drains that are cleaned during the day. After being initially weighed, the sample is then mixed and allowed to dry over several days. After a week, the sample is measured to determine the:

- Dry weight of the sample (to compute wet to dry mass conversion)
- Fraction of the sample that is sediment, organic matter or trash.

A subsample of the dominant fraction of the sample (e.g., sediment, organic matter) is then sent to a laboratory to measure its average carbon, nitrogen and phosphorus content.

The resulting data is submitted in the annual MS4 report, and may be used to adjust default values in the local storm drain cleaning SOP.

Section 8. Future Research and Management Needs

8.1 Panel's Confidence in its Recommendations

One of the key elements of the BMP Review Protocol is that each expert panel should express its confidence in the BMP removal rates that they ultimately recommend (WQGIT, 2014). The panel concluded that its recommendations are based on a much stronger scientific foundation than the previous panel estimate in 2011. It does acknowledge that gaps still exist about the fate and transport of nutrients and sediment from streets, and that the panel had to rely heavily on stormwater models to define the probable impact of different street cleaning scenarios.

The panel agreed that its recommended credit should be reevaluated by a new panel when better research data on seasonal sweeping performance or other practices, such as leaf collection, become available in the next few years.

8.2 High Priority Research Recommendations

The panel identified the following high priority research recommendations to close the remaining gaps in our understanding of the street and storm cleaning practices.

1. The panel noted that only one street cleaning research study has been conducted in the Bay watershed in the last decade. Consequently, more local data are needed on the particle size distribution and nutrient content of street solids and sweeper wastes across the Bay watershed. Given that the verification protocol calls for periodic local sub-sampling of these parameters, it will be helpful to set up a data-sharing mechanism across the watershed. In addition, locals may need better guidance on the best methods to collect and analyze the samples, and provide adequate quality assurance and quality control.

2. More research is needed on the fate, transport, and processing of leaf litter and other organic detritus in urban streets to determine its significance as a nutrient source. If it is found to be significant, further research on whether more intensive sweeping or catch basin cleanouts during fall leaf drop could provide a real water quality impact. This research could have a major influence in shaping the next generation of street cleaning programs.

3. Tracer studies are needed to assess the mobility of the different particle sizes found in street solids and how this influences their delivery from the street to the gutter and from the storm drain to the urban stream corridor. The tracers should look at both the mineral and organic fractions of street solids, as well as seasonal factors.

4. Field testing would help define the sediment and nutrient pick-up efficiency of the next generation of street sweeping technology, under real world conditions.

5. Further testing is recommended to determine whether street and storm drain cleaning could be an effective strategy to reduce toxics, chloride, trash, gross solids from urban watersheds. The research should focus on how effective the practices may be in keeping these pollutants out of local waterways, and helping to meet TMDLs for trash and toxics.

6. More research should be focused on the sediment and trash reduction capabilities of catch basins under various cleaning scenarios, as well as basic investigations of whether the traditional catch basin design could be improved or optimized for greater retention.

8.3 Future Implementation Considerations

The panel identified several priorities to improve local capability to modify their existing street and storm drain cleaning programs to maximize the amount of pollutants that they remove from local waters and the Chesapeake Bay.

- Develop more detailed sampling guidance and standard operating procedures to support the proposed verification protocols for street and storm drain cleaning.

- Establish a support website for MS4s across the Chesapeake Bay watershed on street cleaning, which provides updated guidance, standard reporting forms, a downloadable version of the spreadsheet, and list of sweeper models that are eligible for higher credit. The website might also include an interface for users and practitioners to share their verificationsamples.

- Offer training and technical assistance to local governments to upgrade their sweeping programs to provide more water quality benefits (e.g., workshops and/or webcasts that describe the new credits, show how to use the spreadsheet, techniques to report and verify the practice).

- Provide an annual forum for MS4 fleet managers to exchange tips on how to streamline their sweeper programs. The forum might also focus on route optimization software, WinSLAMM model training, and enhanced operator skills training. The forum could showcase how GIS can be utilized to optimize removal by street cleaning, by screening for street types, curb and gutter drainage, ADT, adjacent land use and other mapping layers.

8.4 Phase 6 Watershed Model Recommendations

The panel endorses the creation of a new land use in the next generation of the Chesapeake Bay Watershed Model that represents the impervious cover associated with transport land uses (i.e., streets, roads and highways). The new transport land use should have a higher target loading for total nitrogen, and will provides a maximum cap on the total area within a jurisdiction that can be swept.

The proposal for a transport land use is consistent with the overall urban land use recommendations for Phase 6 of the CBWM made by Sample et al (2015), as well as the decisions of the CBP Land Use and Modeling Workgroups.

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Note: References denoted with three asterisks (***) were part of the literature review analyzed by the original expert panel (CWP, 2006a).

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Appendix A
Summary of 5.3.2 STREET SWEEPING Practice

Status: This credit was approved by a CBP BMP Expert Panel in March of 2011

Definition: Frequent street sweeping of the dirtiest roads and parking lots within a community can be an effective strategy to pick up nutrients and sediments from street surfaces before they can be washed off in stormwater runoff.

Technical Issues: The basic data for defining the credit were initially developed by Law et al (2008) based on a Baltimore monitoring study and a nationwide literature review of prior street sweeping studies.

Recommended Process: The first and most preferred option is the **mass loading approach**, whereby the mass of street dirt collected during street sweeping operations is measured (in tons) at the landfill or ultimate point of disposal.

Step 1*:* Determine the hopper capacity of your current sweeper technology

Step 2*:* Weigh the street solids collected to develop a simple relationship between street solid mass (in tons) to hopper capacity

Step 3*:* Keep records on the annual mass of street solids collected from qualifying streets

Step 4*:* Convert tons into pounds of street solids (multiply by 2000), and converted to dry weight using a factor of 0.7

Step 5*:* Derive your nutrient reduction credit by multiplying the dry weight of the solids by the following factors:

- Lbs of TN = 0.0025 pounds of dry weight sweeping solids
- Lbs of TP = 0.001 pounds of dry weight sweeping solids

These factors are based on sediment enrichment data reported by Law et al (2008), adjusted from original mg/kg values of 1200 (TP) and 2500 (TN)

Step 6*:* Compute the TSS reduction credit by multiplying the annual mass of dry weight sweeping solids by a factor of 0.3. This correction eliminates street solids that are greater than 250 microns in size, and therefore cannot be classified as total suspended solids. This factor was developed by the BMP panel and reflects particle size data from two recent street sweeping studies. SPU (2009) estimated TSS removal from street sweeping that was approximately 20% of the total dry sweeping solids load recovered. The particle size distribution for recovered street sweeping solids by Law et al. (2008) showed approximately 30% of the recovered solids in this TSS size range (i.e. ≤ 250 μm) by mass.

The second accepted method is **the qualifying street lanes method**.

Step 1: Each locality reports the number of qualifying lane miles they have swept during the course of the year.

Step 2: Qualifying lane miles are then converted into total impervious acres swept by multiplying the miles (5280 feet) by the lane width (10 feet) and dividing by 43,560. If both sides of the street are swept, use a lane width of 20.

Step 3: Multiply the impervious acres swept by the pre-sweeping annual nutrient load using the Simple Method unit loads (Schueler, 1987).

TP = 2.0 lbs/impervious acre/year
TN = 15.4 lbs/impervious acre/year

Step 4: Multiply the total pre-sweep baseline load by the pickup factors shown in Table A-1 to determine the nutrient and sediment load credit for street sweeping.

Table A-1 Multipliers to Reflect Effect of Street Sweeping on the Baseline Load [1]

Technology	TSS	TP	TN
Mechanical	.10	.04	.04
Regenerative/Vacuum	.25	.06	.05

[1] interpolated values from weekly and monthly street sweeping efficiencies as reported by Law et al (2008)

Qualifying Conditions for Street Sweeping Nutrient Reductions: The nutrient reductions only apply to an enhanced street sweeping program conducted by a community that has the following characteristics:

- An urban street with an high average daily traffic volume located in commercial, industrial, central business district, or high intensity residential setting.
- Streets are swept at a minimum frequency of 26 times per year (bi-weekly), although a municipality may want to bunch sweepings in the spring and fall to increase water quality impact.
- The reduction is based on the sweeping technology in use, with lower reductions for mechanical sweeping and higher reductions for vacuum assisted or regenerative air sweeping technologies.

Local Tracking, Reporting and Verification: Localities will need to maintain records on their street sweeping efforts using either method, and provide a certification each year as to either the annual dry solids mass collected or the number of qualifying street miles that were swept.

Appendix B.
Supplementary Data Tables

Table B-1: Comparison of General Particle Size Distribution of Street Solids				
Study	**Coarse**	**Medium**	**Fine**	Cutoffs
Sorenson 2013	30	61	9	2/.125
Sorenson 2013	15	71	14	2/.125
CSD, 2010	14	79	7	2/.075
CSD, 2010	17	79	4	2/.075
CSD,2010	16	78	7	2/.075
SPU, 2009	19	73	8	2/.075
SPU, 2009	24	68	8	2/.075
SPU, 2009	11	78	11	2/.075
Selbig et al 2007	15	77	8	2/.125
Selbig et al 2007	12	77	11	2/.125
Law et al 2008	16	65	19	Approximate
Pitt and Bissonette, 1984	24	66	10	1/.063
Pitt and Bissonette, 1984	24	64	12	1/.063
Wasbusch, 2003	27	67	9	1/.063
Terstriep et 1982	43	52	5	1/.063
Sartor and Boyd,72	31	55	14	1/.063
GRAND MEAN *	**19.9**	**65.3**	**9.2**	
* numbers do not add up to 100% due to rounding				

Table B-2 Nutrient Content of Street Dirt Measured Around the Country (mg/kg)			
Location	Citation	TN	TP
Seattle, WA (S)	SPU et al 2010	3297	690
Seattle, WA (U.S)	SPU et al 2010	3313	439
San Diego, CA	CSD, 2011	518	239
San Diego CA	CSD, 2011	495	199
Baltimore	Law et al 2008	2163	1034
Boston, MA	Sorenson, 2012	ND	500
Boston MA	Sorenson, 2012	ND	700
Grand Mean: TN: 1957 TP: 543			

Table B-3 Nutrient Content of Sweeper Waste Measured Around the Country (mg/kg)			
Location	Citation	TN	TP
Seattle WA	SPU et al 2009	3090	648
Seattle WA	SPU et al 2009	3170	633
Seattle, WA	SPU et al 2009	3540	516
San Diego, CA	CSD, 2011	1136	260
Delaware	Walch, 2006	900	150
Delaware	Walch, 2006	657	290
Delaware	Walch, 2006	799	395
Florida	Sansalone et al, 2011	430	381
Florida	Sansalone et al, 2011	832	374
Florida	Sansalone et al, 2011	546	350
Grand Means TN: 1510 TP: 400			

Table B-4 Nutrient Content of Catch Basin Solids Measured Around the Country (mg/kg-dw)			
Location	Citation	TN	TP
Seattle WA	SPU et al 2009	3380	708
Seattle WA	SPU et al 2009	4300	817
Seattle, WA	SPU et al 2009	6745	817
Baltimore, MD	Law et al 2008	781	585
Baltimore,MD	Law et al 2008	3480	980
Maryland	MWCOG, 1993	1760	267
Maryland	MWCOG, 1993	1719	365
Florida	Sansalone et al, 2011	467	301
Florida	Sansalone et al, 2011	773	423
Florida	Sansalone et al, 2011	785	537
Nationwide	Schueler, 1994	2931	583
Bellevue WA	Pitt and Bissonette, 1984	2100	769
Grand Means TN: 2435 TP: 596			

Appendix C Conformity with BMP Review Protocol

The BMP review protocol established by the Water Quality Goal Implementation Team (WQGIT, 2014) outlines the expectations for the content of expert panel reports. This appendix references the specific sections within the report where the panel addressed the requested protocol criteria.

1. Identity and expertise of panel members: See Table in Section 1, page 8

2. Practice name or title: The street cleaning practice (SCP) refers to 11 different street cleaning scenarios that vary based on sweeper technology and the number of sweeping passes per year. The pollutant reductions associated with the 11 SCPs are provided in Table 17 (p. 41) and the specific definitions for each street cleaning scenario are provided in Table 15 (p. 36). The storm drain cleaning practice is defined in Section 6.4.

3. Detailed definition of the practice: See Section 2 in the report for a comprehensive list of the definitions used in the report (pages 11-13).

4. Recommended N, P and TSS loading or effectiveness estimates: The percent removal rates for sediment and nutrients for *each street cleaning practice* (SCP) are provided in Table 17. One curb-mile swept is assumed to be equivalent to one acre of impervious cover. The *storm drain cleaning credit* is expressed as the actual pounds of sediment and nutrients that are captured and properly disposed, as calculated by the equations provided in Section 6.4 (page 44).

5. Justification of selected effectiveness estimates: The panel conducted an extensive review of the available science to justify its street cleaning removal rates (see Section 4), as well as supervising the development of WinSLAMM model adapted for the Chesapeake Bay watershed to determine removal rates over a wide range of street cleaning scenarios (see Section 5). The storm drain cleaning credit is empirically derived based on a national review of the nutrient enrichment of solids removed from BMP and catch basin sediments.

6. List of references used: The panel reviewed more than 100 papers and reports, which are provided in the *References Cited* section, beginning on page 51.

7. Detailed discussion on how each reference was considered: See Sections 3 to 5 of the report for the panel's assessment of the existing literature.

8. Land uses to which BMP is applied: In the Phase 5.3.2 model, the practices apply to the impervious cover land use. In Phase 6, the practice will be restricted to the new transport impervious cover land use.

9. **Load sources that the BMP will address and potential interactions with other practices**: Both practices reduce loads from urban impervious cover, although the reduction is calculated in two different ways (see sections 6.1 and 6.4, respectively). The issue of how street and storm drain cleaning interact with other structural BMPs in the same watershed is discussed at length in Section 6.2

10. Description of pre-BMP and post-BMP circumstances and individual practice baseline: Since it is an annual practice, there is no need for a baseline. Street and storm drain cleaning BMPs were not considered in the original calibration of the Phase 5.3.2 CBWM.

11. Conditions under which the BMP works/not works: The WinSLAMM model showed a wide range of scenarios in which the street cleaning practice does not work. These options were excluded from the panel's final recommendations.

12. **Temporal performance of BMP including lag times between establishment and full functioning:** The pollutant reductions occur in the same year as the street or storm drain cleaning efforts occur.

13. Unit of measure: For street cleaning: curb-lanes mile swept for each SCP.
For storm drain cleaning: pounds removed.

14. Locations in CB watershed where the practice applies:
Anywhere in the Bay watershed where the qualifying conditions are met.

15. Useful life of the BMP: One year

16. Cumulative or annual practice: Annual practice. The street or storm drain cleaning credit needs to be reported every year.

17. Description of how BMP will be tracked and reported: See Section 7 for a discussion on how jurisdictions track, report and verify the street and storm drain cleaning practice to the Bay Program (page 41- 45). Additional details can also be found in Appendix E "Technical Requirements for Scenario Builder"

18. Ancillary benefits, unintended consequences, double counting: The panel noted that an advanced sweeping technology program could have the potential ancillary benefit of reducing loads of gross solids, trash and toxic contaminants to local waterways, as well as improving the safety and appearance of both green and conventional streets. The panel could not identify any other unintended consequences associated with effective local street and/or storm drain cleaning programs. The Panel evaluated the potential double counting issue involving the interaction of street cleaning and structural BMPs within the same catchment (Section 6.2), and concluded it was not a significant issue.

19. Timeline for a re-evaluation of the panel recommendations. The panel did not set a timeline to reconvene, but did note that it may be advisable to do so when more research on the seasonal influence of leaf drop, cleaning and removal is completed in the Bay watershed.

20. Outstanding issues: The panel outlined its confidence in its recommendations in Section 8.1, its priority research recommendations in Section 8.2 and recommendations to improve local implementation in Section 8.3.

Appendix D Consolidated Meeting Minutes of the Panel

Appendix E Technical Requirements to Enter Practices in Scenario Builder