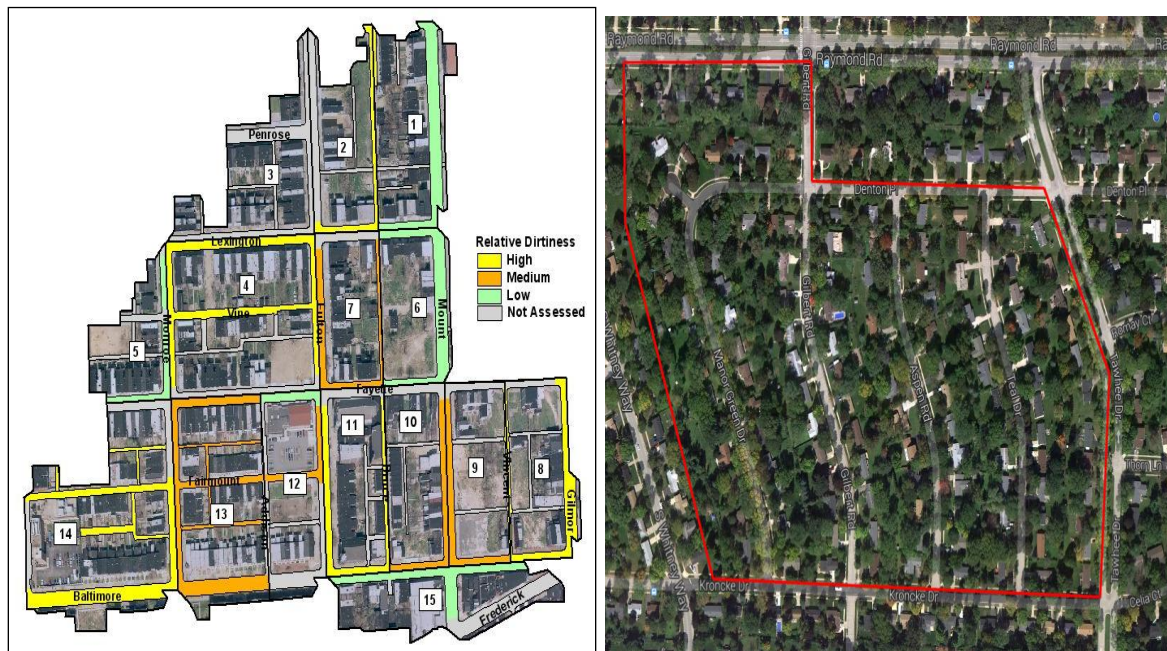


# Recommendations of the Expert Panel to Define Removal Rates for Street and Storm Drain Cleaning Practices

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## FINAL REPORT



January 11, 2016

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# Expert Panel Report on Street and Storm Drain Cleaning

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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

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## 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 credited 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 may merit 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 both 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

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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 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, given the dearth of studies that showed measurable water quality change in receiving waters. The panel elected to use the Source Loading and Management Model for Windows (WinSLAMM), 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.

Pollutant Reductions Associated with Different Street Cleaning Practices					
Practice #	Description <sup>1</sup>	Approx Passes/Yr <sup>2</sup>	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					
<sup>1</sup> See Table 15 for the codes used to define street cleaning frequency					
<sup>2</sup> Depending on the length of the winter shutdown, the number of passes/yr may be 10 to 15% lower than shown					

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A spreadsheet tool was used to define percent nutrient removal rates by applying a nutrient enrichment ratio 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 Chesapeake Bay watershed model.

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. 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 their state stormwater agency. Localities may 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.

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 stormwater outfalls. 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 catch basins that trap the greatest organic matter loads, streets with the greatest overhead tree canopy and/or outfalls that generate higher 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 that are captured.



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

The panel agreed that the two existing methods for calculating pollutant reduction for street cleaning 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 better data to improve the effectiveness of future street and storm drain cleaning programs. In addition, the panel outlined several priorities to improve the capacity of communities to implement programs that can maximize pollutant reduction to local waterways and the Chesapeake Bay.

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## Section 1: Charge and Membership of Expert Panel

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In 2011, an expert panel recommended sediment and nutrient removal rates for intensive street sweeping in 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 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 tested the performance of a new generation of street cleaners, and have measured 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 were developed in response to several TMDLs in northeastern states which may be transferable 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.



## Expert Panel Report on Street and Storm Drain Cleaning

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The initial charge of the panel was to review all of the available science on the nutrient and sediment removal performance associated with the regular 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 expert panel memo, along with its supporting research and literature review (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 street cleaning frequencies that were less than that recommended by the original panel (i.e., 26 times per year).
- The technical support for pollutant reduction protocols developed in other regions of the country.
- Studies measuring the nutrient content of sediment and leaf detritus at various points in the urban landscape.
- Specific operational definitions for each of the four management practices defined earlier and the qualifying conditions under which a locality can receive a nutrient and/or sediment reduction credit.
- 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.

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- 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 Watershed Model (CBWM) and the Scenario Builder tool.

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

## Section 2: Key Definitions

This analysis of street and storm drain cleaning practices draws on complex terminology used by the scientific and practitioner communities. To assist the reader, the panel agreed to the following definitions 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 use of 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.

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- *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:*

- *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.

### *Catch Basin Terminology*

- *Catch Basin*: A type of storm drain inlet that contains a sump. Typically a catch basin is constructed using a pre-cast concrete barrel installed vertically, with a cast-iron grated lid at the street surface.
- *Curb-cut Inlets*: A cut in the curb that allows stormwater runoff to enter into the inlet through bypassing the inlet grate.
- *Drop Inlet*: A type of storm drain inlet that does not contain a sump.
- *Deep Sump Hooded Catch Basin*: A type of catch basin that contains a sump that is at least 4 feet deep and a hood.

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- *Hood:* A 90° elbow installed at the outlet of a catch basin to reduce floatable material from the discharge.
- *Inlet:* a structure located below the ground surface with a grated lid at street level that drains road or parking lot runoff. Inlets are typically constructed adjacent to a road curb, and is covered by a cast iron grated lid with multiple openings (each opening no more than 2-inch square). The runoff is directed to drain pipes, then via an outfall to surface waters. May also be referred to as a storm drain.
- *Storm Drain Manhole:* A bend structure connecting stormwater drainage pipes that contains a solid cast-iron cover at street level.
- *Sump:* A trap located below the outlet invert of a catch basin. The purpose of the sump is to collect solids in stormwater runoff.

### *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. 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 was that nearly all communities operate some kind 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 <sup>1</sup>	Loading rates
<b>Street selection</b>	45%	5%	45%	40%	10%	5%
<b>Frequency</b>	30%	5%	35%	35%	10%	5%

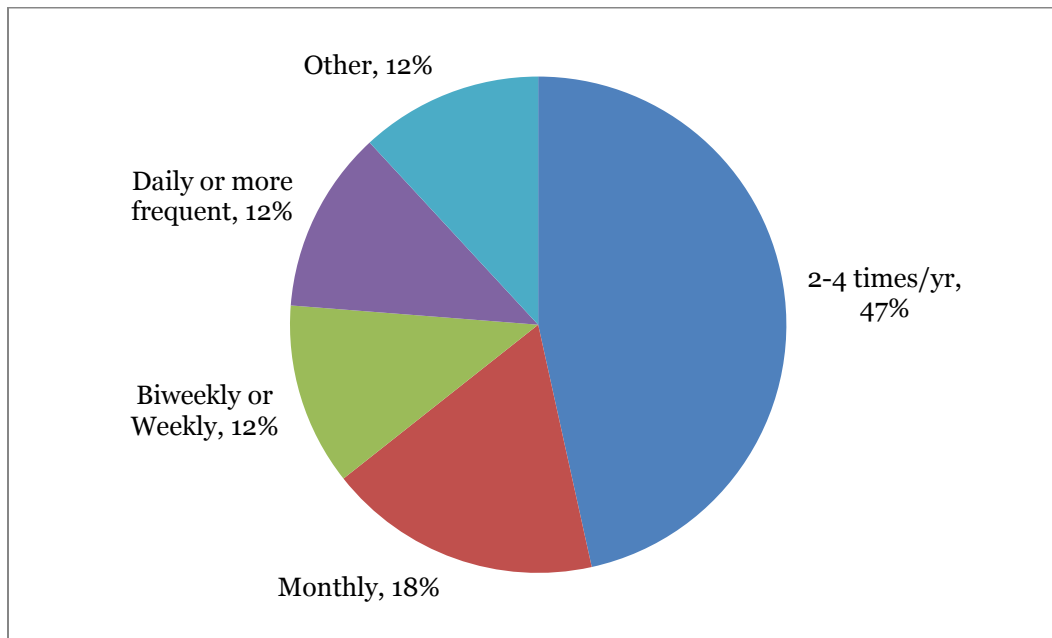
<sup>1</sup>. ESA = **environmentally sensitive area**

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 were 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 cleaned 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.

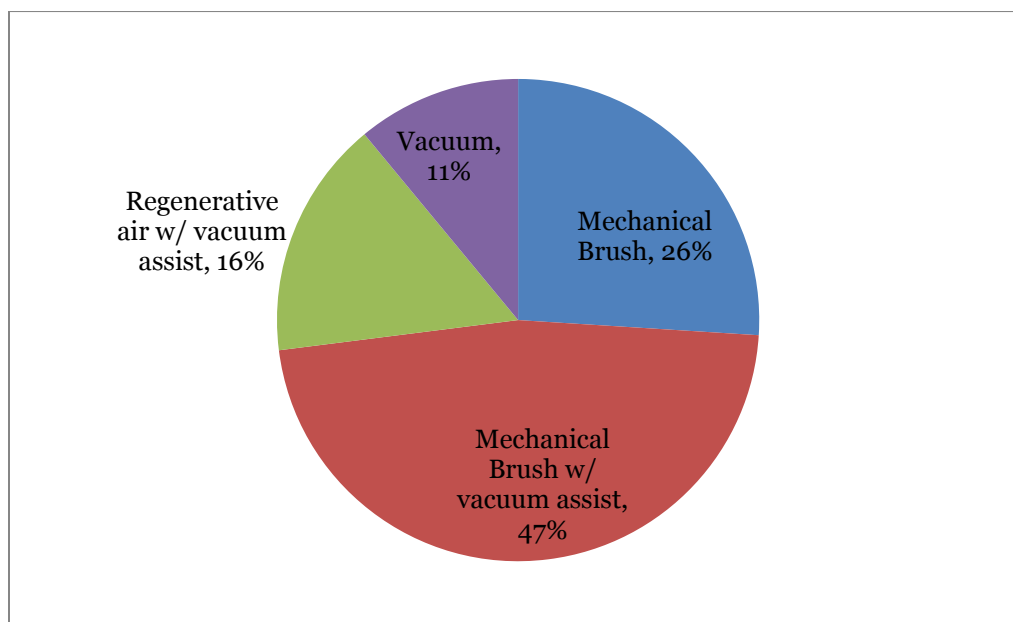


## Expert Panel Report on Street and Storm Drain Cleaning



**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 vacuum-assisted sweepers or regenerative air sweepers have higher 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

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## Expert Panel Report on Street and Storm Drain Cleaning

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### 3.2 Catch Basin Cleanouts

The CWP survey also looked at how frequently communities clean out their storm drains (CWP, 2006b). The key finding was that only 40% of communities clean out storm drains on a regular schedule, with the remainder cleaning them only in response to public complaints or actual flooding problems. Overall, communities conduct storm drain cleanouts very infrequently -- 94% of communities clean them out less frequently than once a year (Table 2). Improving water quality was not cited as the primary objective of local storm drain cleanout programs.

<b>Table 2. Storm drain cleanout frequency in the Chesapeake Bay (n=19)</b>	
<b>Frequency</b>	<b>Percent</b>
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 of street solids 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 local street cleaning efforts that are reported for credit. Consequently, there has been some confusion about how to report and track annual street cleaning efforts.

This is evident in the street cleaning implementation data that are submitted by the Bay states to the Chesapeake Bay Program each year (Table 3). Jurisdictions can report 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.

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**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
<b>2009</b>	1 ac			218,000 lbs	632 ac
<b>2010</b>	1,631 ac			227,000 lbs	
<b>2011</b>	1,540 ac		619 ac		75,385,792 lbs
<b>2012</b>	1,539 ac		413 ac		
<b>2013</b>	1,526 ac	79,541 lbs	3,240,489 lbs	190,000 lbs	218,677 lbs
<b>2014</b>	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: pervious and impervious cover. 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 <sup>1</sup>	1,269,030
Average TN Load <sup>2</sup>	15.5 lbs/ac/yr
Average TP Load <sup>2</sup>	1.93 lbs/ac/yr
Average TSS Load <sup>2</sup>	0.65 t/ac/yr
Key Inputs	Air Deposition, Build-up/Wash-off, No Groundwater Interaction, No Direct Interaction with Pervious Cover
<sup>1</sup> Acres, as reported in most recent CBWM version 5.3.2	
<sup>2</sup> 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 solids and sweeper wastes, as well as their nutrient, carbon and toxic content.
- (c) The effect of different street sweeping scenarios on different street types across the country.

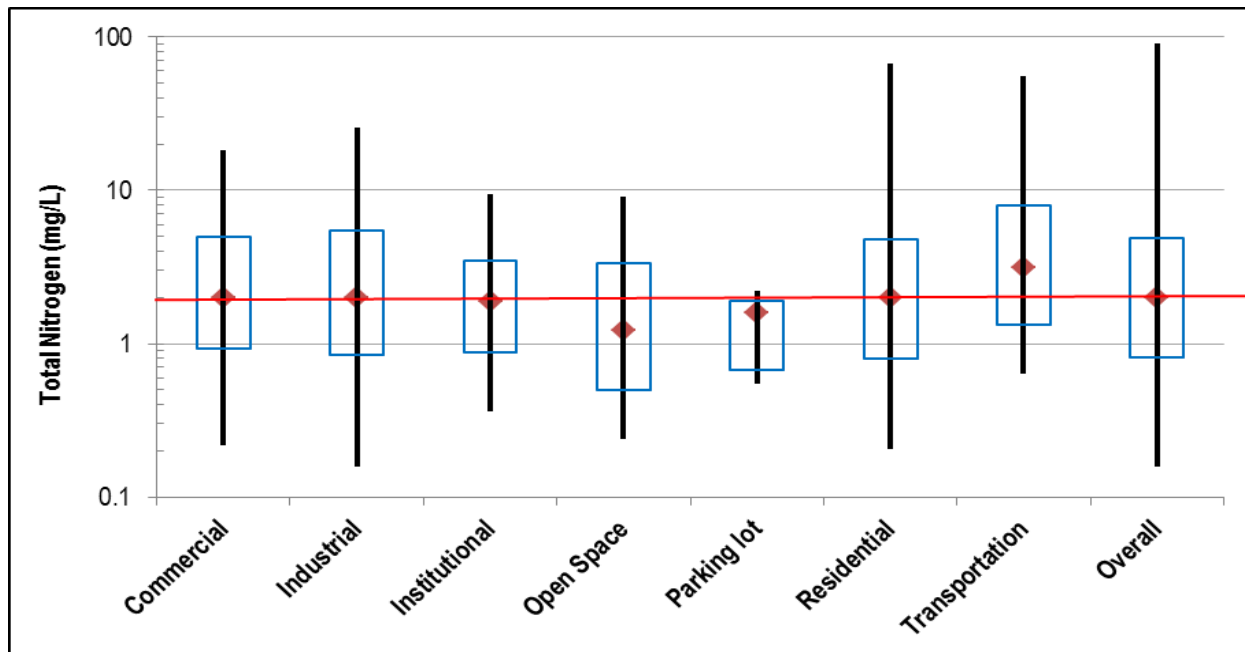
#### **4.1 Nutrient and Sediment Concentrations in Road Runoff**

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.

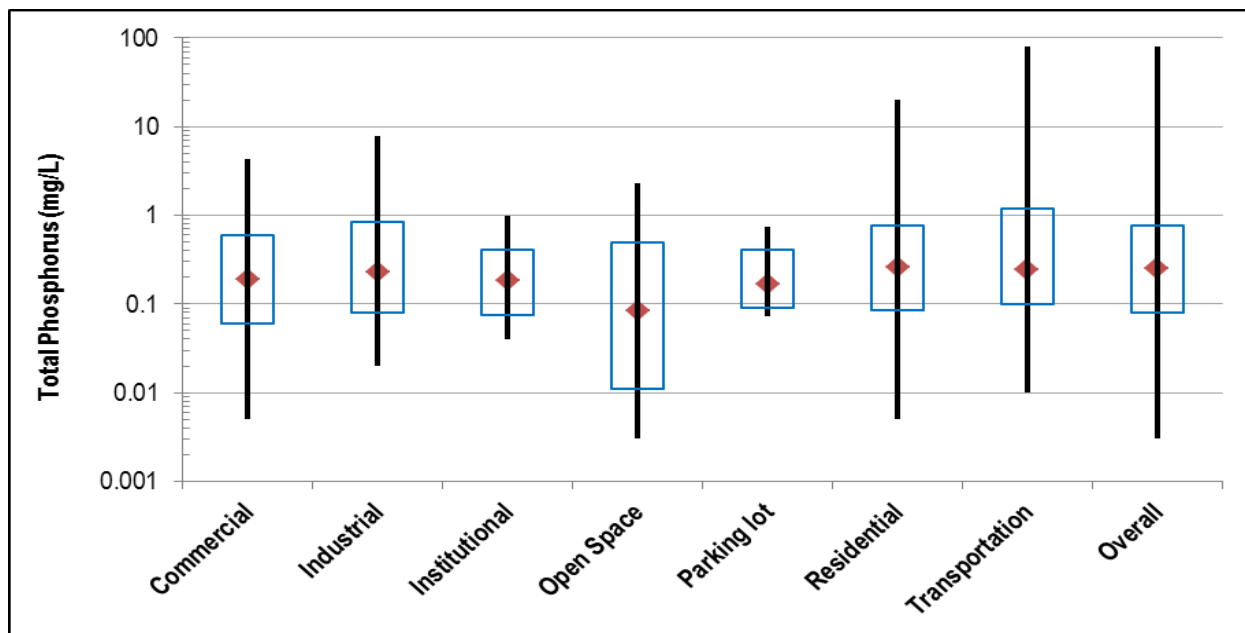
Some of the key findings from the analysis are shown in Figure 3, which compares the TN concentrations in stormwater runoff measured for different types of impervious cover. The mean TN concentration for transport land uses, which includes roads, streets and highways, was 3.11 mg/l, as compared to 1.98 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 appears to be related to 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, median TP concentration among the different urban land uses are very similar.

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**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 event mean concentrations (EMCs) of nutrients and sediment in stormwater runoff. Table 5 explores the general relationship of between stormwater EMCs as a function of ADT.

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The most pronounced relationship is for TN, which steadily climbs as ADT increases. The relationships for TSS and TP were 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 or vegetated 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	<b>64</b>	<b>2.0</b>	<b>0.25</b>

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	Cambridge, MA	Sorenson, 2013	Multi-fam. resid
467	Cambridge, 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

<sup>1</sup> One curb mile is roughly equivalent to one acre of impervious cover

US = Unswept, RAS= Regenerative Air Sweeper, Resid = Residential



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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).

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 actually become a net source of sediment when they are dislodged by contact with a sweeper brush (Smith, 2002).

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 1000 microns), about 10% as fine-grained (less than 62 microns) and about 20% as coarse-grained.

<b>Table 7. Comparison of General Particle Size Distribution of Street Solids <sup>1</sup></b>			
GRAND MEAN of 9 Studies <sup>2</sup>	<b>Coarse</b>	<b>Medium</b>	<b>Fine</b>
	<b>19.9</b>	<b>65.3</b>	<b>9.2</b>
<sup>1</sup> numbers do not add up to 100% due to rounding			
<sup>2</sup> 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 they will reach the storm drain system or not. 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 removing 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,

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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, 2013, Kalinosky, 2013, Selbig, 2014).

The panel reviewed recent literature on the interaction between leaf detritus, street solids and nutrient dynamics in urban watersheds. 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.

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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 leaf mass within one year (Hobbie et al, 2013). Baker et al (2014) observed that rapid nutrient leaching occurred 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, published 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 values from across the country. The degree of nutrient enrichment measured for street solids 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 by 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 are 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 may be 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.

**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)
<b>Mid-Point of Data</b>	--	<b>0.07</b>	<b>0.20</b>	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
<b>Mid-Point of Data</b>	--	<b>0.12</b>	<b>1.11</b>	Calculated

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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 can be applied to practices that trap 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. Table 12 summarizes the trace metal content measured in sweeper wastes, which are roughly twice as high as those observed in urban soils.

<b>Table 12.</b> 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
<b>MEAN</b>		<b>80</b>	<b>97</b>	<b>176</b>
Urban Soils (Pouyat et al, 2007)		35	89	91

<b>Table 13.</b> 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	

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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, phthalates and pyrethoid pesticides, as well as very high chloride levels due to winter road 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 (CWP, 2006a). Ten key studies that were published after 2006 are profiled in the ensuing section.

Overall, the new studies produced 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 or receiving waters. Once again, the study designs were not robust enough to collect enough stormwater samples to show a statistically significant difference before and after treatment. Instead, 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 (NURP) 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 frequency in which it used. CWP estimated that nutrient reduction for street sweeping was lower, ranging 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

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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 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. Street solid pick-up efficiencies ranged between 50 to 80% for the two advanced sweeper options tested, but were negligible for mechanical broom sweepers.

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 collected from this study, and the model was calibrated to the time series of street solid loading data.

**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



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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 by an unspecified degree.

**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 and 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 much 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 measured 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 total solids removal of approximately 3 to 19%, total particulate solids removal of 4.2 to 32% and total phosphorus removal of 1.4 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

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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 Summary of Storm Drain Cleaning Research

This section reviews the limited research available to examine the pollutant removal benefits associated with storm drain and/or catch basin cleanouts. As with street cleaning, much of the research has focused on the nutrient content of the sediment and organic matter trapped in the storm drain, but few studies have discerned a statistical improvement in stormwater quality, either due to the presence of catch basins, or based on regular cleanouts.

Mineart and Singh (1994) evaluated the effect of monthly catch basin cleaning in California, and reported potential reductions of 3 to 12% of sediment and trace metals (nutrients were not investigated). Pitt and Bissonnett (1984) reported that twice a year cleanouts of catch basins in Bellevue, Washington could reduce total solids in urban runoff by 10 to 25% and reduce nutrients and organic matter by 5 to 10%.

The results of recent research are more equivocal. For example, UNH SC (2012) investigated the performance of a deep sump catch basin receiving runoff from a nine-acre parking lot in Durham, NH. The study evaluated how the catch

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basin reduced sediment and nutrient concentrations as they passed through the practice. While they detected about a 10% reduction in TSS loads due to the deep sump catch basin, they did not find any statistical difference in nitrate or total phosphorus concentrations during monitored storm events.

MWCOG (1993) monitored the effectiveness of oil grease separators, a type of drain inlet with special sediment trapping chambers, in removing sediments, nutrients and metals from urban runoff. The Maryland study demonstrated that sediments and attached pollutants trapped within the chambers were frequently re-suspended and effective pollutant removal required very frequent cleanouts. The study also reported that sediments trapped in the inlets were highly enriched with nutrients, trace metals and hydrocarbons.

High nutrient content for catch basin sediments are frequently reported elsewhere in the literature (see Table 20 and Table B-4 for a comparative review of nutrient levels in traditional catch basin sediments).

Law et al (2008) presented data on the composition and nutrient content of sediments cleaned out from catch basins without sumps, as measured in Baltimore County, MD. The study noted that coarse-grained sediments and organic matter predominated in the catch basins sampled. Law et al (2008) reported that most of the nitrogen was associated with the sediment particles, whereas organic matter (leaves) were an important source of phosphorus in catch basin sediments. Coarse-grained material comprised more than 85% of catch basin solids (trash represented ~10% of the material cleaned out from the inlets). The nutrient enrichment data derived from Law et al (2008) was used to define the 2011 CBP storm drain cleaning credit (CSN, 2011).

SPU (2009) examined the interaction between street cleaning and catch basin cleanouts in the same subwatershed. The study team monitored sediment accumulation in catch basins located on residential and industrial streets, some of which were cleaned and some that were not. They found that frequent street cleaning by advanced cleaning technology did not change the solids accumulation rate in the test catch basins, which is not surprising given the low solids reduction reported for both practices. SPU (2009) did not assign a pollutant removal rate for catch basin cleaning for local TMDLs.

Smith (2002) evaluated the performance of a catch basin to remove suspended sediment and nutrients along an interstate highway in Boston that was also swept by mechanical broom sweepers. Smith (2002) found that 85 percent of the material trapped in the catch basin was coarse-grained (i.e., >0.25 mm in diameter). Fine-grained material was seldom deposited in the catch basin because its retention time was too short for gravity to separate particles (the median retention time was seven minutes during the median storm). Smith (2002) also reported that the suspended sediment concentrations discharged from the catch basins did not substantially change before and after they were cleaned out each year.

Smith (2010) investigated the performance of six deep sump catch basins with different hood configurations in reducing gross solids, oil and grease and total petroleum

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hydrocarbons along an interstate highway in Boston, Massachusetts. The median efficiency of the deep sump basin catch basins for trapping gross solids was 44% over the six month study. Smith (2010) noted that the gross solids accumulation rate for deep sump catch basins ranged from 6 to 69 lbs/curb mile. The gross solids that were trapped were predominately natural organic matter (~75%), followed by plastic materials (~20%) and cigarette butts (~5%). The catch basins did not appear effective at removing oil and grease or petroleum hydrocarbons from urban runoff.

Two other studies showed little pollutant removal benefit associated with catch basin cleaning. Irgang et al (2001) sampled stormwater quality during 11 storm events in catch basins located in a residential roadway network, and could not find a statistical improvement in stormwater quality between sites where catch basins had been cleaned or not cleaned. The study team qualified their finding by noting that their study was of short duration and subject to significant variability in pollutant concentrations. Dammel et al (2001) also found that catch basin cleanouts did not improve stormwater quality in successive storm events in Southern California, although once again it was a short term study.

Based on the foregoing data, the expert panel concluded that there was insufficient data to support assigning a positive sediment or nutrient removal rate for catch basins, regardless of sump or hood configuration, due to their minimal hydraulic residence time. The panel took a more conservative approach that nutrient removal credit was only warranted when the mass of nutrient-rich catch basin sediments was measured and physically removed from the storm drain system.

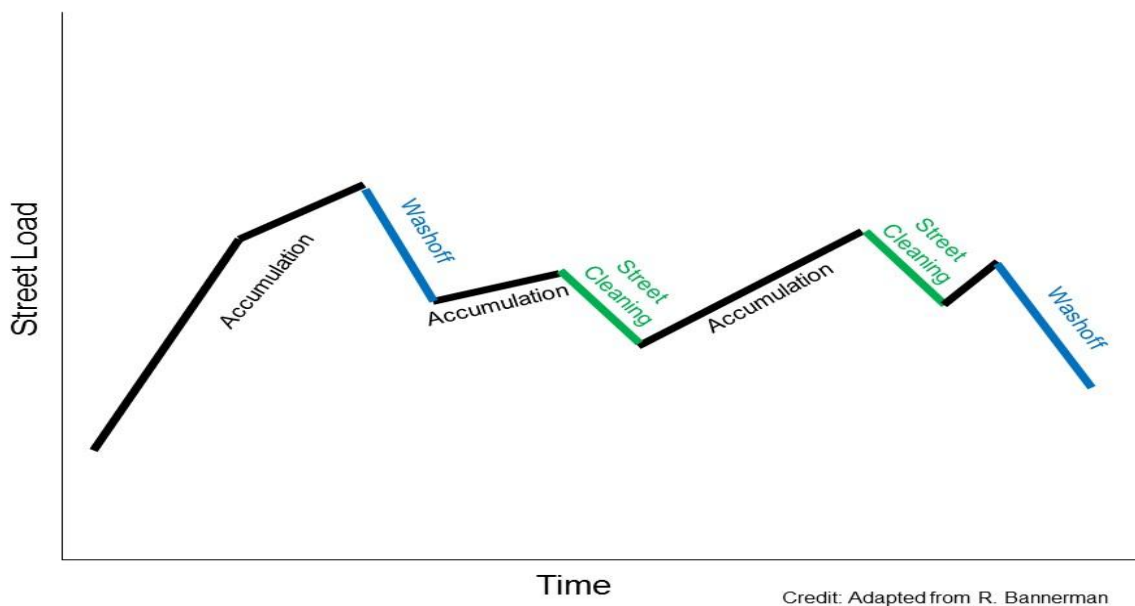
### **4.8 Key Panel Conclusions About Recent Street Cleaning Research**

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.*

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



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

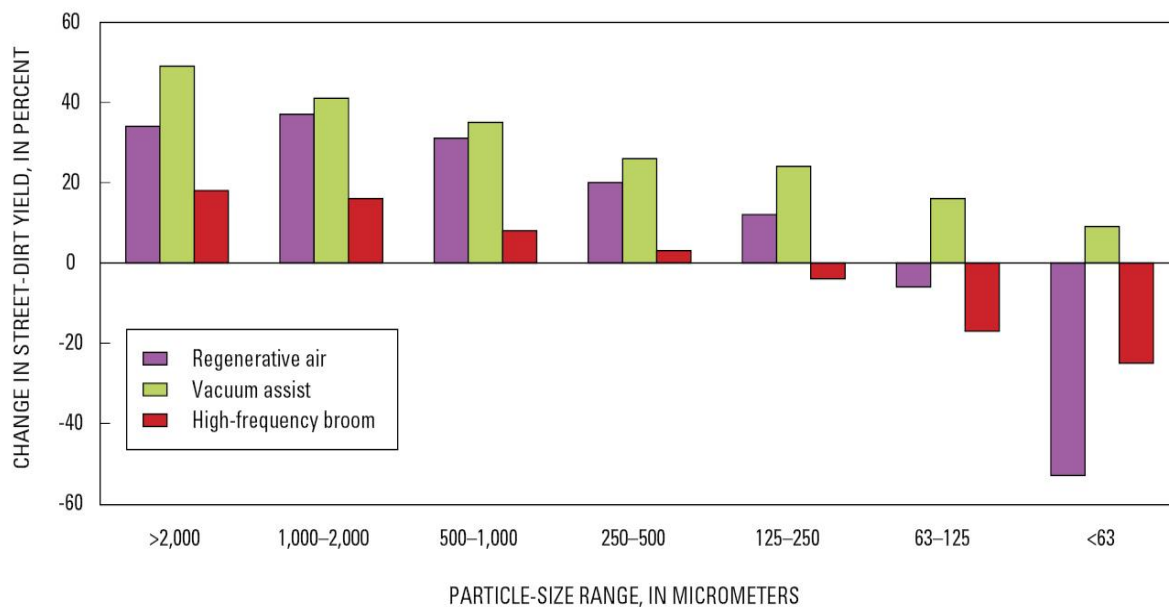
On average, storm events occur every 4 to 5 days in the Bay watershed, which creates the "sawtooth" pattern in street solid accumulation shown in Figure 5. On dry days, solids build up on the street surface, only to be washed off during storm events, unless a sweeper happens to come sooner. Given that 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 street solid loads that are picked up by mechanical broom sweepers. Researchers have found that mechanical broom sweepers are effective in picking up coarse-grained particles, but have a low overall sediment pick-up efficiency. Mechanical broom sweepers 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 concluded that mechanical broom sweepers can play a role in removing gross solids, trash and litter from street surfaces.

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 percentage of fine particles on the street after they pass.

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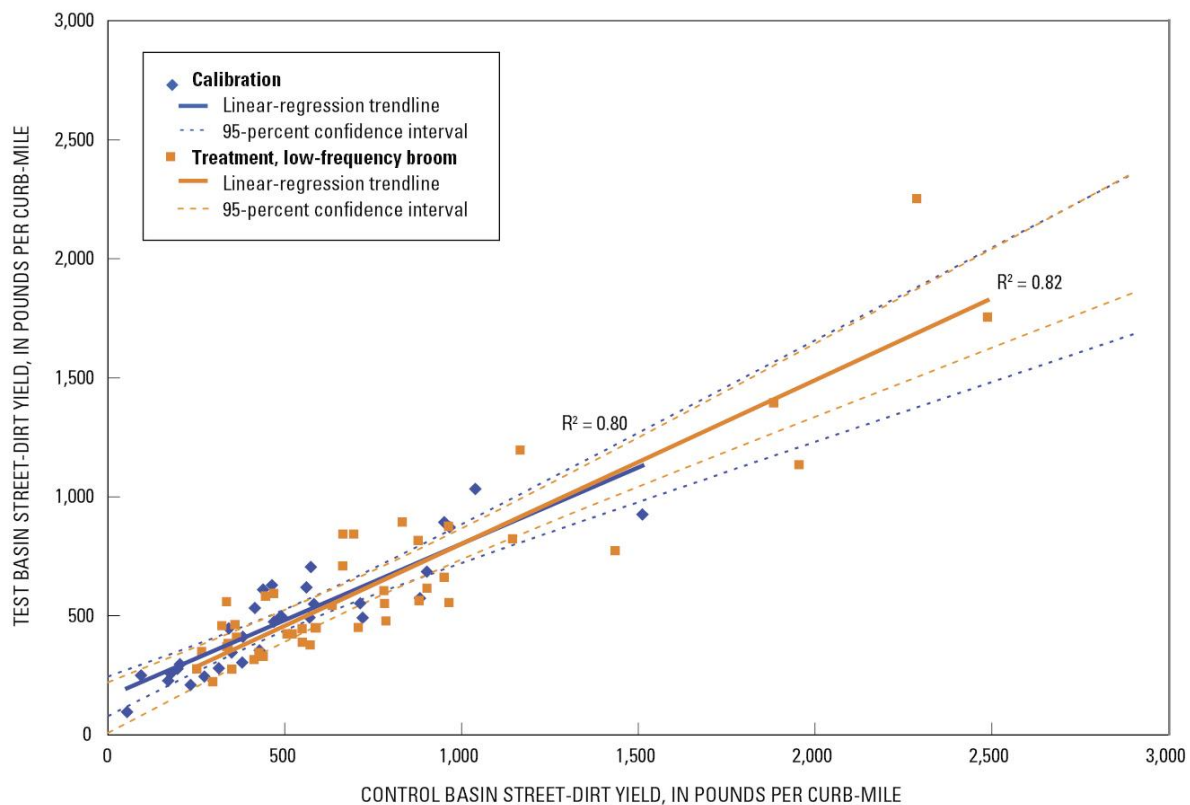
**Figure 6** Comparative pick up efficiency of three types of sweepers (Selbig and Bannerman, 2007).

Mechanical broom sweeper actually dislodge 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, Smith, 2002, Waschbush, 1999).



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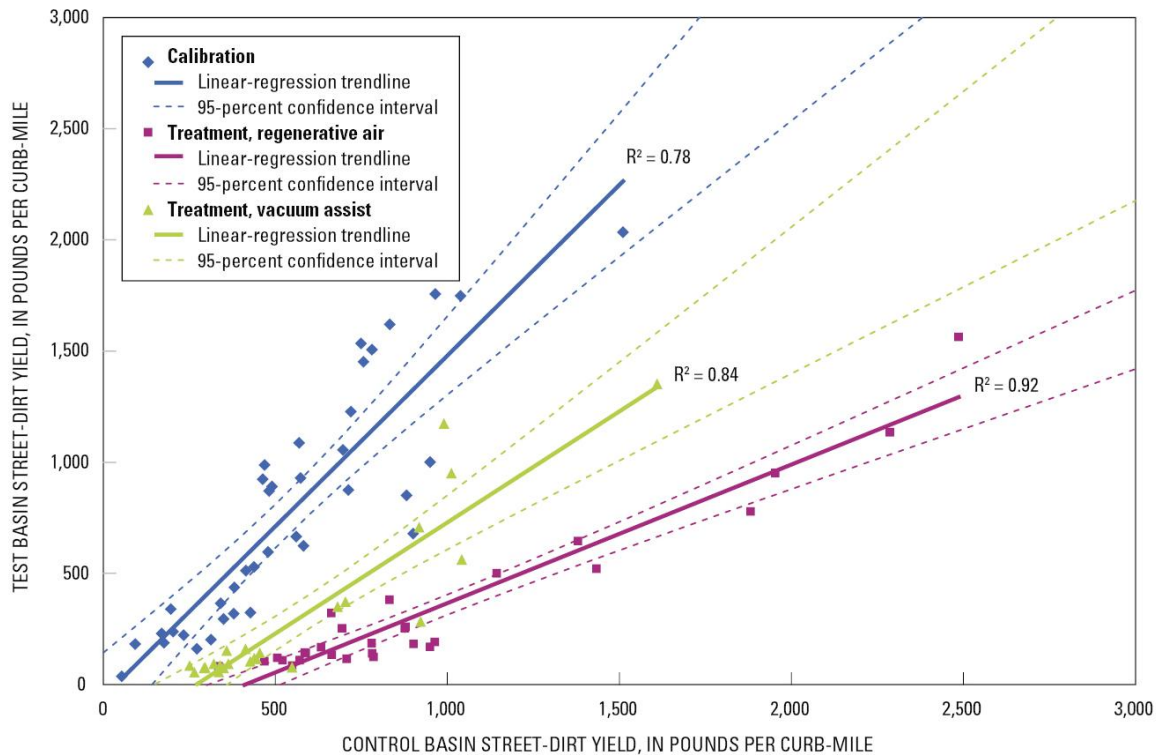
**Figure 7.** Response in weekly average street dirt load for control street (un-swept) and a street cleaned with mechanical broom sweeper in Madison, WI (Source: Selbig and Bannerman, 2007).

### 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 found a handful of monitoring studies that compared sediment pick-up efficiency between the two advanced street cleaning technologies -- regenerative air and vacuum assisted sweepers. Selbig and Bannerman (2007) showed that regenerative air sweepers had high sediment pick-up efficiencies that were generally comparable to those achieved by vacuum-assisted sweepers. Their finding was reinforced by three other street cleaning monitoring studies (Sorenson, 2013, SPU, 2009 and CSD, 2010). Consequently, the expert panel concluded that both qualify as Advanced Sweeper Technologies (AST) and thereby can earn higher pollutant removal rates than traditional mechanical broom sweepers.

*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 sweeper 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.

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Other practitioners have noted that pickup efficiency can be influenced by the skills 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).

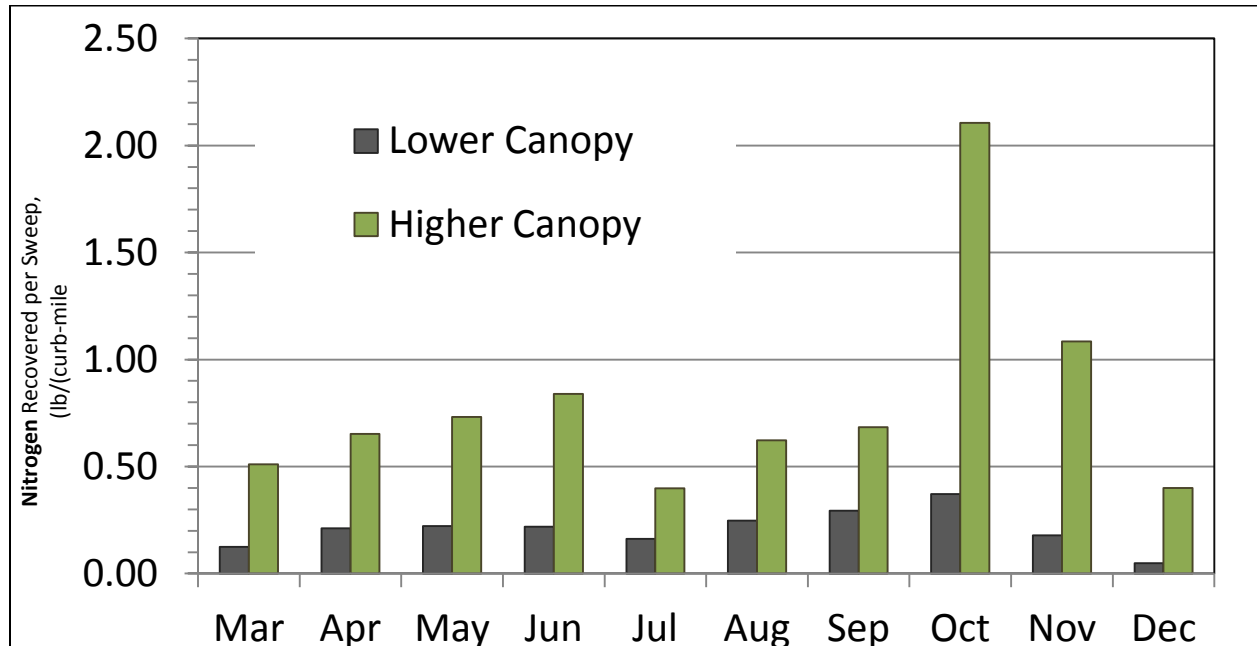
*8. The adjacent tree canopy influences the organic and nutrient loads on the street on a seasonal basis, but the management implications for this phenomenon are unclear.*

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).

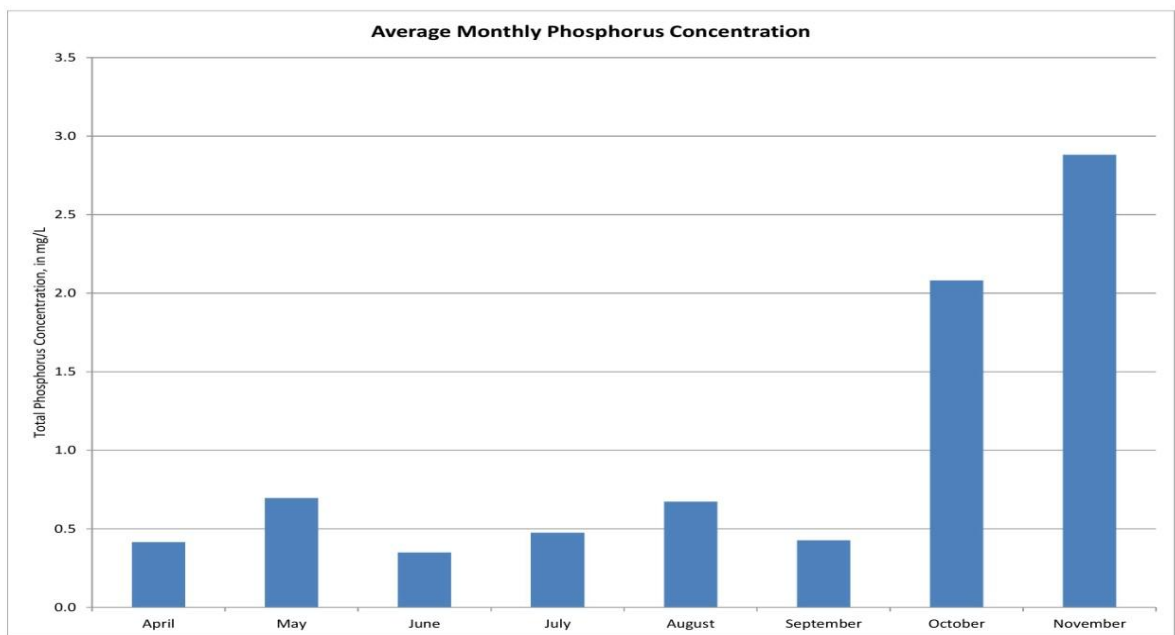
A good example of the influence of tree canopy on nitrogen recovery in sweeper waste is shown in Figure 9. This Minnesota study found the highest N recovery in the late fall, with a second and smaller peak occurring in the late spring (Kalinosky, 2013). Figure 10 shows a similar pattern between tree 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 into storm drains and ultimately reaches the stream corridor.

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**Figure 9:** Effect of Street Tree Canopy on N Levels in Sweeper Waste (Kalinovsky, 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).

## Expert Panel Report on Street and Storm Drain Cleaning

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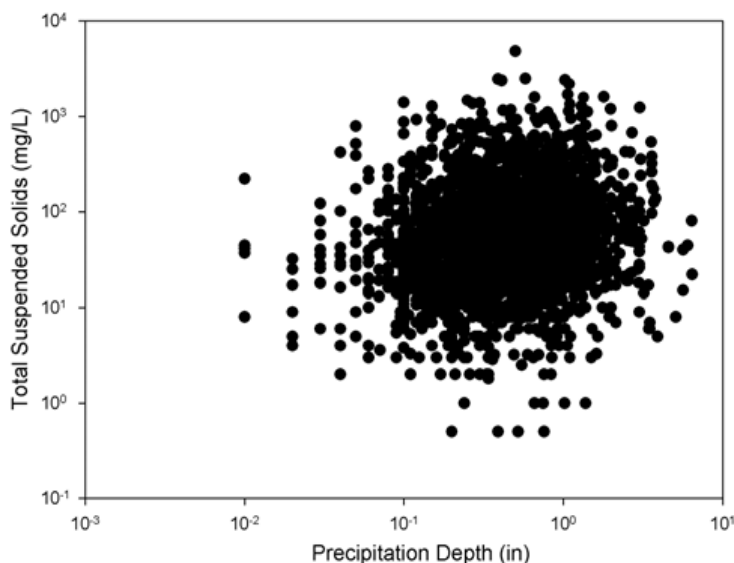
The panel concluded that our understanding of the fate, transport and processing of leaf litter in urban watersheds is still emerging, and there were insufficient data to quantify its significance as a nutrient source. In addition, the panel could find no monitoring data to establish whether more intensive street cleaning coinciding with fall leaf drop might have a definitive water quality impact.

The panel agreed that further research on this urban nutrient management strategy should be a top priority and should 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 then 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)

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Figure 11 illustrates the variability in sediment concentrations as a function of rainfall depth (on a logarithmic scale) during more than 3,500 runoff events included in 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 for street cleaning treatments.

**Table 14.** Samples Required to Detect Change Given EMC Variability

Pollutant	Coefficient of Variation <sup>1</sup>	Approx. No. of Samples Required <sup>2</sup>
TSS	1.8	250
TN	1.0	75
TP	1.3	150

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

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

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 researchers have now shifted to hydrologic simulation models to evaluate the water quality impacts of street cleaning.

The panel agreed that modeling was the best means to derive reliable sediment and nutrient reduction rates associated with street cleaning at this time. The advantage of a modeling is that it allows managers to assess 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 the Chesapeake Bay watershed (Version 10.1.0, P&V Associates 2014; Pitt and Voorhees 2000). WinSLAMM is a 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 from different urban 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 regions as a tool to determine TP reduction credits for lake TMDLs (Upper Midwest and New England). 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](http://www.chesapeakestormwater.net)).

The street cleaning module was calibrated and verified to real street solids datasets. The Bay application 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.



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The Panel elected to not to use WinSLAMM to explicitly simulate nutrients, and instead estimated them based on empirical nutrient enrichment ratios for street solids (see Section 4.4).

<b>Table 15.</b> Adapting the WINSLAMM Model for the Chesapeake Bay Watershed	
<b>Bay rainfall data.</b> 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.	
<b>East Coast input data files</b> 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	
<b>Four different street types</b> were simulated to represent in different land uses that had curb and gutter drainage systems:	
<p><i>Single-family residential:</i> 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.</p> <p><i>Commercial (80 percent impervious):</i> 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.</p> <p><i>Ultra-urban downtown (95 percent impervious):</i> Multistory buildings. Two-lane urban roads with parallel parking on both sides of the street, sidewalks, and 25 mph speed limit.</p> <p><i>Arterial highway:</i> 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</p>	
<b>Three different sweeping start/stop dates</b> to reflect regional differences in climate across the watershed:	
<p>Sweeping occurs over the entire year</p> <p>Sweeping suspended December 1, restarts March 15</p> <p>Sweeping suspended December 15, restarts February 15</p>	
<b>Six different fixed sweeping schedules</b>	
<p>2PW = 2 passes per week</p> <p>1PW = 1 pass every week</p> <p>1P2W = 1 pass every 2 weeks</p>	<p>1P4W = 1 pass every 4 weeks</p> <p>1P8W = 1 pass every 8 weeks</p> <p>1P12W = 1 pass every 12 weeks</p>
<b>Four seasonal sweeping schedules</b> (more intensive in Spring or Fall)	
<p>S1: Spring – One pass every week from March to April. Monthly otherwise</p> <p>S2: Spring – One pass every other week from March to April. Monthly otherwise</p> <p>S3: Spring and fall – One pass every week (March to April, October to November). Monthly otherwise</p> <p>S4: Spring and fall – One pass every other week during the season. Monthly otherwise</p>	
<b>Two Levels of Sweeper Technology</b>	
MBC = Mechanical broom cleaning	VAC = Vacuum assisted cleaning
<b>Four Options for Street Parking Density and No Parking Enforcement</b>	
For more details, consult the technical memo (Tetra Tech, Inc., 2015)	

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The screenshot displays the 'Street Cleaning Control Device' window. It includes fields for 'Land Use: Residential' and 'Total Area: 3.92'. The 'Source Area' is set to 'Street Area 1'. The 'Select' section has two radio buttons: 'Street Cleaning Dates' (unselected) and 'Street Cleaning Frequency' (selected). Below this is a table with 10 rows for 'Line Number', 'Street Cleaning Date', and 'Street Cleaning Frequency'. To the right of the table is a list of frequency options with radio buttons, where '3 Passes per Week' is selected. Further right, the 'Type of Street Cleaner' section has two radio buttons: 'Mechanical Broom Cleaner' (selected) and 'Vacuum or Regenerative Air Cleaner' (unselected). Below that, the 'Street Cleaner Productivity' section has two radio buttons: 'Coefficients based on street texture, parking density and parking controls' (selected) and 'Other (specify equation coefficients)' (unselected). The selected option has input fields for 'Equation coefficient M (slope, M<1)' with the value '0.68' and 'Equation coefficient B (intercept, B>1)' with the value '310'. The 'Parking Densities' section has five radio buttons: 'None', 'Light', 'Medium', 'Extensive (short term)', and 'Extensive (long term)' (selected). The 'Are Parking Controls Imposed?' section has two radio buttons: 'Yes' (unselected) and 'No' (selected). At the bottom, there are buttons for 'Continue', 'Clear', 'Cancel Edits', and 'Delete Control'. The 'Model Run Start Date' is '03/01/81' and the 'Model Run End Date' is '11/30/81'. There is also a field for 'Final cleaning period ending date (MM/DD/YY):' and a checkbox for 'Apply the first year of sweeping dates to all subsequent years'.

Line Number	Street Cleaning Date	Street Cleaning Frequency
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

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

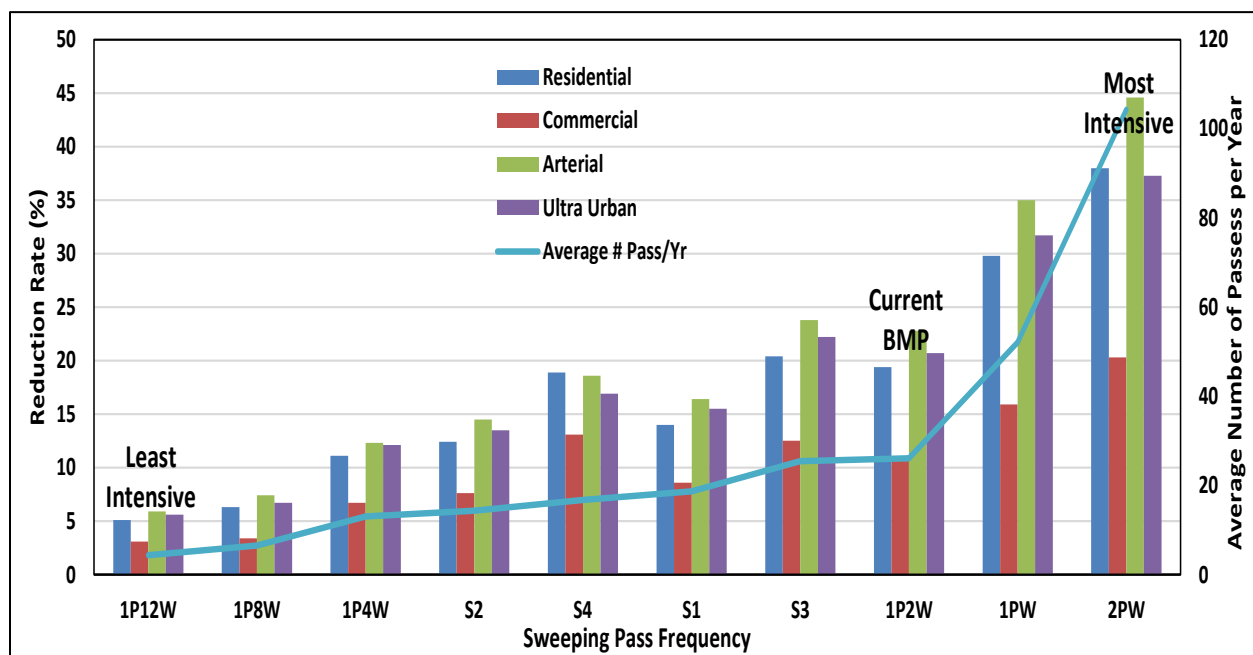
### Section 5.2 Key Findings from the WinSLAMM Modeling.

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.

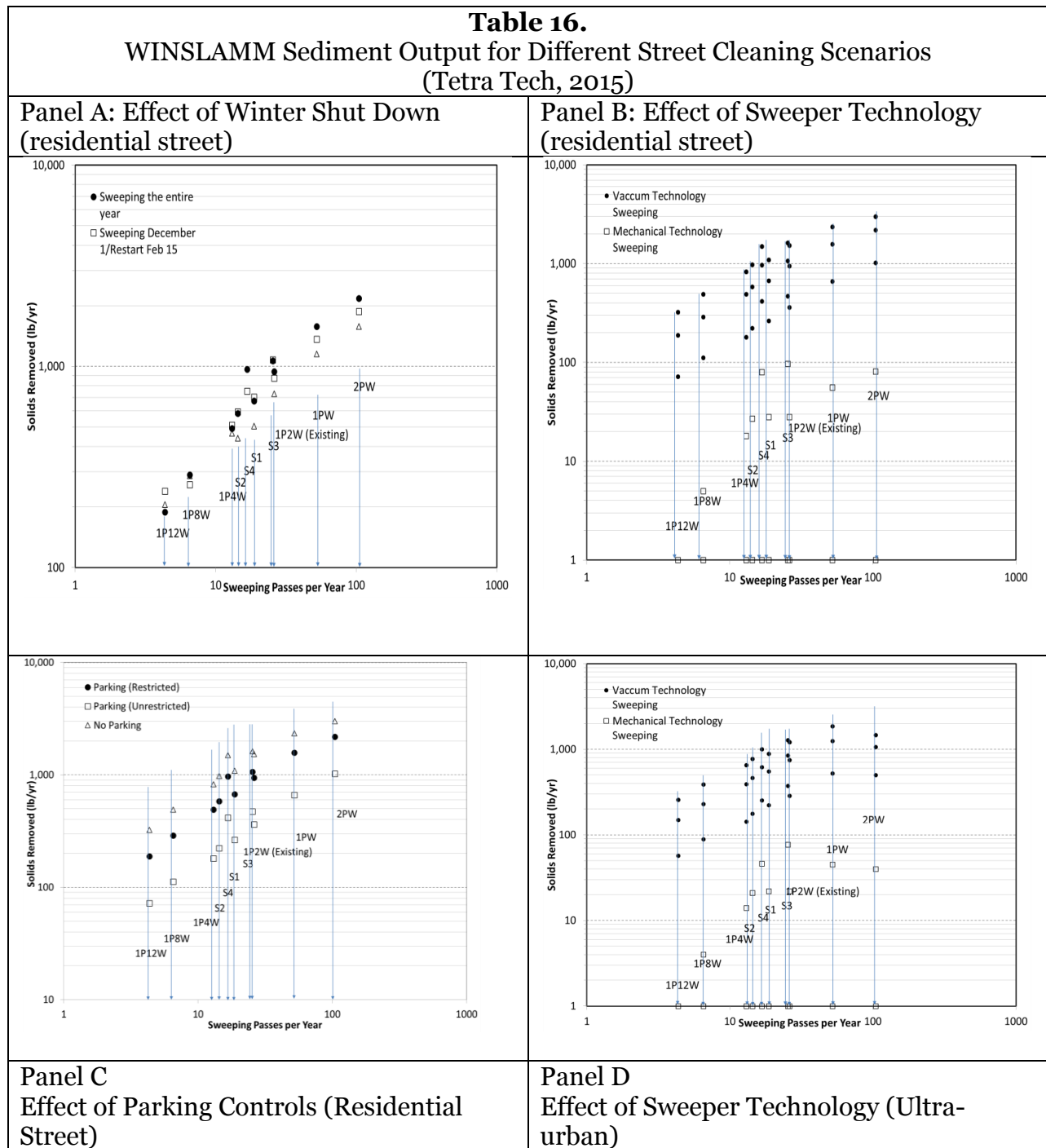
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- Figure 13 also indicates that sediment reduction is influenced by the type of road that is swept. Arterial, ultra-urban and residential streets had higher sediment reduction rates than commercial streets. The effect of street type on sediment reduction, 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.
- S3 was found to be the most effective seasonal cleaning scenario (one pass every week from March to April and October to November, and monthly sweeping the rest of the year).
- Another seasonal impact involves the length of the winter shut down period, which varies between the top and the bottom of the Bay 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 the winter sweeping shutdown was very modest, compared to areas here sweeping can be done year round (Panel A in Table 16).



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

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## 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 simulated 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. Credit is also provided for cleaning municipal and commercial parking lots (in this case, the acres of parking lot swept are reported, and converted to lane miles using the one acre = one curb lane mile rule of thumb.

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).

<b>Table 17. Pollutant Reductions Associated with Different Street Cleaning Practices</b>					
Practice #	Description <sup>1</sup>	Approx Passes/Yr <sup>2</sup>	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					
<sup>1</sup> See Table 15 for the codes used to define street cleaning frequency					
<sup>2</sup> Depending on the length of the winter shutdown, the number of passes/yr may be 10 to 15% lower than					

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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 or reliability of its predicted sediment reduction rates.

**Table 18.** Default Nutrient Enrichment Factor Applied in Spreadsheet \*

Enrichment Factor	% P	% N	Notes
<b>Urban Street Solids</b>	<b>0.07</b>	<b>0.20</b>	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 estimate the credit, 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 (%) <sup>1</sup>			Mass Removed (lbs) <sup>2</sup>		
		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
<sup>1</sup> From Table 17, and assume one curb mile equals an acre <sup>2</sup> 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							

## Expert Panel Report on Street and Storm Drain Cleaning

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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 the effect was 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 one 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.



### 6.4 Storm Drain Cleaning Credit

The panel recommended a sediment and nutrient reduction credit for solids that are directly removed from storm sewer systems (i.e., catch basins, within storm drain pipes or captured at the storm drain outfall). The storm drain cleaning credit does not apply to sediment removal operations that occur during ditch maintenance along open section roads. It does apply to sediment removal operations that occur in open, concrete-lined conveyance channels.

The credit promotes innovative practices such as outfall 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 are 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 the 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 captured over the course of a year is reported for credit and is expressed in terms of pounds of sediment and nutrients.

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

- (1) To maximize reduction, efforts should target catch basins that trap the greatest organic matter loads, streets with the greatest overhead tree canopy and/or outfalls with high 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 the mass of the sediments and/or organic matter that are removed. Appendix F provides an example of an SOP developed by Baltimore County, MD that may serve as a useful template for tracking storm drain inlet cleaning.
- (3) Material must be properly disposed so that it cannot migrate back into the watershed.

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**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	<b>0.06</b>	<b>0.27</b>	See Table B-4
Organic Matter/Leaf Litter	<b>0.12</b>	<b>1.11</b>	See Table 11

\* Multiply the mass (dry weight) of sediment removed from the storm drain (in pounds) by a factor of 0.006 and 0.027, for TP and TN, respectively. The result is the lbs/year of TP and TN credited.

**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 provide additional documentation about their street cleaning effort in the annual MS4 report they submit to their state stormwater agency.

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 may need to 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)

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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-* All panel commendations on tracking and verification are advisory in nature, and are not binding on any state. Individual Bay states can provide alternate verification methods for street cleaning, as long as they satisfy the general verification principles agreed to by the Chesapeake Bay Program Partnership (CBP, 2014).

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:

- Volume of sweeper waste collected in the hopper, truck or dumpster (in cubic feet)
- Total wet mass of the sweeper waste (measured)
- 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

These measurements can be used to better estimates of the:

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

This data 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*-- All panel commendations on tracking and verification are advisory in nature, and are not binding on any state. Individual Bay states can provide alternate verification methods for storm drain cleaning, as long as they satisfy the general verification principles agreed to by the Chesapeake Bay Program Partnership (CBP, 2014).

The panel recommended a process to verify the storm drain cleaning practice that is similar to the approach used for street cleaning. 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.

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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. Some useful guidance on sampling methods can be found in Stack et al (2013) and Kalinosky et al (2014). The resulting data can be submitted in annual MS4 reports, 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 street and storm cleaning practices.

1. The panel noted that only one street cleaning research study was conducted in the Bay watershed over 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 watershed. Given that the verification protocol calls for periodic local sub-sampling of these parameters, it is recommended that a data-sharing mechanism be established across the watershed. In addition, municipalities and other governmental entities will require better guidance on the best methods to collect and analyze 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 they are found to be significant, more research could determine whether intensive sweeping or catch basin cleanouts during the fall leaf drop might have a real water quality impact.
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



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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. One clear need is more research on the sediment pickup efficiency on streets and highway shoulders that lack curb and gutters.
5. Further testing to determine whether street or storm drain cleaning could be an effective strategy for keeping toxics, chloride, trash or gross solids out of local waterways, and meeting local 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 verification samples.
- 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.



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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.  $\leq 250 \mu\text{m}$ ) by mass.

## Expert Panel Report on Street and Storm Drain Cleaning

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).

$$\begin{aligned} \text{TP} &= 2.0 \text{ lbs/impervious acre/year} \\ \text{TN} &= 15.4 \text{ lbs/impervious acre/year} \end{aligned}$$

**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 <sup>1</sup>			
Technology	TSS	TP	TN
Mechanical	.10	.04	.04
Regenerative/Vacuum	.25	.06	.05
<sup>1</sup> 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.

# Expert Panel Report on Street and Storm Drain Cleaning

## Appendix B. Supplementary Data Tables

<b>Table B-1: Comparison of General Particle Size Distribution of Street Solids</b>				
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
<b>GRAND MEAN *</b>	<b>19.9</b>	<b>65.3</b>	<b>9.2</b>	
* numbers do not add up to 100% due to rounding				

<b>Table B-2 Nutrient Content of Street Dirt Measured Around the Country (mg/kg)</b>			
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
<b>Grand Mean: TN: 1957 TP: 543</b>			

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**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
<b>Grand Means TN: 1510 TP: 400</b>			

**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
<b>Grand Means TN: 2435 TP: 596</b>			

# Expert Panel Report on Street and Storm Drain Cleaning

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## Appendix E. Technical Requirements to Entering Street and Storm Drain Practices in Scenario Builder and the Chesapeake Bay Watershed Model

**Presented to the WTWG for Review and Approval: January, 2016**

**Background:** In accordance with the *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model* (WQGIT, 2015) each BMP expert panel must work with CBPO staff and the Watershed Technical Workgroup (WTWG) to develop a technical appendix for each expert panel report.

The purpose of this technical appendix is to describe how the Street and Storm Drain Cleaning Expert Panel's recommendations will be integrated into the Chesapeake Bay Program's modeling tools including NEIEN, Scenario Builder and the Watershed Model.

### *Part 1: Technical Requirements for Reporting and Crediting Street Cleaning BMPs*

#### **Q1. How are street cleaning BMPs defined in the Chesapeake Bay Watershed Model?**

**A1.** Street cleaning is defined by the expert panel as a program that uses either mechanical broom sweepers, regenerative-air sweepers or vacuum assisted sweepers to pick up solids off the street surface in an effort to improve water quality. Street cleaning is broken into 11 distinct BMPs based upon the type of sweeping technology and how frequently it is used.

#### **Q2. What types of street cleaning programs can be reported for credit in the Phase 6.0 Watershed Model?**

**A2.** The Panel used the WinSLAMM model to assess over 960 different street cleaning scenarios and elected to consolidate the model results into eleven different street cleaning practices that may be reported for credit in the Chesapeake Bay Program's modeling tools.

The street cleaning practices are defined primarily by whether or not the program uses advanced street cleaning technology and by the cleaning frequencies. The following 11 street cleaning practices may be reported to NEIEN for credit in a progress scenario or reported to the CBPO for credit in a planning scenario:



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Practice Number	Technology Type*	Sweeping Frequency
SCP1	Advanced	2 per week
SCP2	Advanced	1 per week
SCP3	Advanced	1 per 2 weeks
SCP4	Advanced	1 per 4 weeks
SCP5	Advanced	1 per 8 weeks
SCP6	Advanced	1 per 12 weeks
SCP7	Advanced	Seasonal 1 or 2**
SCP8	Advanced	Seasonal 3 or 4**
SCP9	Mechanical Broom	2 per week
SCP10	Mechanical Broom	1 per week
SCP11	Mechanical Broom	1 per 4 weeks

\* Advanced technologies include Regenerative-Air Sweepers and Vacuum Assisted Sweepers. Definitions for each technology can be found in Section 2 of the report.

\*\*Seasonal sweeping definitions can be found in Table 15

### **Q3. Which land use categories are eligible to receive nutrient and sediment reduction credit from street cleaning BMPs in the Phase 5.3.2 Watershed Model, and the Phase 6.0 Watershed Model?**

**A3.** In the Phase 5.3.2 Watershed Model, nutrient and sediment reduction credit from street cleaning BMPs would be applied to the “impervious cover” land use. In the Phase 6.0 Watershed Model, nutrient and sediment reduction credits from street cleaning BMPs are applied to the “roads” land use and the “tree canopy over roads” land use.

### **Q4. How much nitrogen, phosphorus and sediment reduction credit are associated with each of the street cleaning practices?**

**A4.** The nutrient and sediment reduction efficiencies are outlined in Table 1:

<b>Table 1. Pollutant Reductions Associated with Different Street Cleaning Practices</b>			
Practice #	TSS Removal (%)	TN Removal (%)	TP Removal (%)
SCP1	21	4	10
SCP2	16	3	8
SCP3	11	2	5
SCP4	6	1	3
SCP5	4	0.7	2
SCP6	2	0	1
SCP7	7	1	4
SCP8	10	2	5
SCP9	1.0	0	0
SCP10	0.5	0	0
SCP11	0.1	0	0

### **Q5. What do jurisdictions need to report to NEIEN in order to receive street cleaning credit?**

**A5.** For street cleaning credit, jurisdictions will need to report the following to NEIEN:

- *BMP Name:* Practice name (e.g. SCP3) that best defines the jurisdiction's street cleaning program.
- *Measurement Name:* Total number of (feet) or (acres) cleaned under the specified street cleaning practice, with no duplication or overlapping
- *Geographic Location:* Qualifying NEIEN geographies including: Latitude/Longitude (preferred as the coordinates of the centroid of the street cleaning route); or County; *or* County (CBWS Only); or Hydrologic Unit Code (HUC12, HUC10, HUC8, HUC6, HUC4, State (CBWS Only))
- *Date of Implementation:* Year the sweeping was done
- *Land Uses:* Impervious Cover (for Phase 5.3.2); Roads or Tree Canopy Over Roads (for Phase 6.0)

### **Q6. Will jurisdictions have the option to report street cleaning practices using the existing street sweeping practice reporting methods established by the 2011 panel, for the 2015, 2016 and 2017 Progress in the Phase 5.3.2 Watershed Model?**

**A6.** Yes. While it is strongly preferred that jurisdictions report street cleaning practices using the new “qualifying lane miles method” outlined in this report, jurisdictions will retain the options to report using the existing “qualifying land miles method” and the existing “mass loading method”, for all remaining Progress years in the Phase 5.3.2 Watershed Model.

### **Q7. Will jurisdictions have the option to report street cleaning practices using the existing street sweeping practice reporting methods established by the 2011 panel, in the Phase 6.0 Watershed Model and Phase 6.0 Historic Data Cleanup?**

**A7.** No. Beginning with 2018 Progress, jurisdictions will only be able to report street sweeping practices using the new “qualifying lane miles method” outlined in this Panel's report.

### **Q8. If a jurisdiction does not know which of the defined street cleaning practices they qualify for, which practice should they submit as a default?**

**A8.** Jurisdictions should report SCP3 as the default street sweeping practice. SCP3 is most consistent with the definition of the existing qualifying lane miles method in the Phase 5.3.2 Watershed Model, and is most likely to be representative of jurisdictions' street sweeping programs.

### **Q9. Are street cleaning practices cumulative or annual BMPs?**

**A9.** All street cleaning BMPs are annual practices and must be reported each year in order to receive nutrient and sediment reduction credit in the CBP modeling tools.

### **Q10. How do street cleaning BMPs interact with other BMPs located within the same catchment in the CBP modeling tools?**

**A10.** Roads treated by street cleaning programs 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.

### *Part 2: Technical Requirements for Reporting and Crediting Storm Drain Cleaning BMPs*

### **Q11. How are Storm Drain Cleaning BMPs defined in the Chesapeake Bay Watershed Model?**

**A11.** Storm drain cleaning is defined by the expert panel as the removal of sediment and organic matter from catch basins in a targeted manner that focuses on water quality improvements. The storm drain cleaning program should 1) 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) be verified using a field protocol to measure the mass or volume of solids collected within the storm drain pipe system; and 3) properly dispose of removed material so that it cannot migrate back through the watershed.

### **Q12. How will states and localities calculate nutrient and sediment reductions for storm drain cleaning practices?**

**A12.** 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

## Expert Panel Report on Street and Storm Drain Cleaning

sample the nutrient and carbon content of the materials they physically remove from the storm drain.

<b>Table 20.</b> 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	<b>0.06</b>	<b>0.27</b>	See Table B-4
Organic Matter/Leaf Litter	<b>0.12</b>	<b>1.11</b>	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.			

### **Q13. How will the modeling tools estimate the actual load reductions from each storm drain cleaning practice?**

**A13.** Storm drain cleaning practices will be treated in the same way as stream restoration practices in the model. This means that storm drain cleaning reductions will apply to loads exiting upslope acres after they have filtered through upslope BMPs. The pounds reduced for each project within a land-river segment will be added together and applied as a reduction at the watershed outlet for each segment. The model simulates further reductions to nutrients between the watershed outlet and the Chesapeake Bay.

### **Q14. What do jurisdictions need to report to NEIEN to receive storm drain cleaning credit?**

**A14.** To receive storm drain cleaning credit, jurisdictions must report the following to NEIEN:

- *BMP Name:* Storm Drain Cleaning
- *Measurement Name:* Aggregate mass of load collected by the storm drain cleaning program over the course of the year, expressed as pounds of sediment and nutrients, as calculated in A5.
- *Geographic Location:* Qualifying NEIEN geographies including: Latitude/Longitude (preferred as the coordinates of the centroid of the street cleaning rout); or County; *or* County (CBWSOnly); or Hydrologic Unit Code (HUC12, HUC10, HUC8, HUC6, HUC4, State (CBWSOnly)
- *Date of Implementation:* Year the storm drain cleaning was done
- *Land Uses:* Approved NEIEN land uses – The default land use group for Storm Drain cleaning BMPs will be UrbanWithCss

### **Q15. Is storm drain cleaning a cumulative or annual BMP?**

**A15.** Storm drain cleaning is an annual practice and must be reported each year in order to receive nutrient and sediment reduction credit in the CBP modeling tools.

**Q16. How do storm drain cleaning BMPs interact with other BMPs located within the same catchment in the CBP modeling tools?**

**A16.** Roads treated by storm drain cleaning programs 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 storm drain 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.

# Expert Panel Report on Street and Storm Drain Cleaning

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## APPENDIX G

**Date:** January 12, 2016

**From:** Tom Schueler  
CBPO Stormwater Coordinator  
Chesapeake Stormwater Network

**To:** Urban Stormwater Workgroup  
Watershed Technical Workgroup

**Re:** Response to Comments on Street and Storm Drain Cleaning  
Expert Panel Report (Revised)

The Expert Panel Report was released on September 18, and a webinar was held on September 29 in which more than 30 individuals participated. The required 30 day comment period under the new joint BMP expert panel review process recently established by the WQGIT expired on Monday, October 19.

The following individuals and organizations provided comments as of October 23:

- Tom Maguire, Justin Shafer and Neely Law (members of expert panel)
- Unidentified individual on webinar
- PA DEP
- MDE SSA
- Chesapeake Bay Foundation
- City of Chesapeake
- Anne Arundel County, MD

This memo summarizes the comments received by the deadline, and presents a technical response. It is organized in three sections:

### **Section 1: Applicability and Qualifying Conditions for the Practice**

**Comment No. 1.** *Does the storm drain cleaning credit apply to sediment removal operations that occur during ditch maintenance along open section roads?*

**Response:** No, it does not. The storm drain cleaning credit only applies to sediment and/or organic matter removed from within the storm drain system (i.e., catch basins, storm drain pipes and/or stormwater outfalls). Given its charge, the panel did not evaluate any research on pollutant removal achieved during rural or agricultural ditch maintenance or retrofits. Other ongoing expert panels and research projects are investigating possible practices to enhance nutrient and sediment removal in agricultural and roadside ditch networks.

## Expert Panel Report on Street and Storm Drain Cleaning

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**Comment No. 2.** *Does the storm drain cleaning credit apply to sediment removal operations that occur in open, concrete-lined conveyance channels?*

**Response:** Yes, the practice is very similar to storm drain pipe or catch basin cleaning and should be credited in the same manner. These channels are located downstream of catch basins and provide an additional opportunity to capture pollutant loads before reaching the urban stream network.

**Comment No. 3.** *Can a community earn the street cleaning credit if it sweeps municipal or commercial parking lots, in addition to streets and roads?*

**Response:** Yes, but generally only when advanced street cleaning technology is used on the parking lot. In the past, most parking lots were swept using older mechanical broom sweepers that earn low or zero credit under this expert panel's recommendation.

Allowing parking lot cleaning will require two minor edits to Appendix E "Technical Requirements to Enter Practice into Scenario Builder". The first involves determining whether parking lots will be assigned to the new transport land use in the Phase 6 CBWM (or not). The second will involve additional text on how parking lot cleaning effort needs to be reported to get credit (e.g., report acres of parking lot swept, and then convert back to lane miles using the 1 acre = 1 curb lane mile rule).

**Comment No. 4.** Can the street cleaning credit be applied to roads and streets without curb and gutters?

**Response:** The expert panel explicitly considered this issue, and determined that there was insufficient monitoring data to determine whether it was effective to sweep streets without curb and gutters. The panel reviewed one study on the topic which is presented on page 21 of their report, and is excerpted below:

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 actually become a net source of sediment when it is mobilized by contact with a sweeper broom (Smith, 2002).

The panel recommended more research be conducted on the effect of sweeping streets and highway shoulders that lack curb and gutters. Until that data becomes available, streets and parking lots without curb and gutter are eligible for credit.

### Section 2: Technical Comments on the Panel Report

**Comment No. 5.** *The expert panel report should include a review of the limited monitoring data on the pollutant removal performance associated with storm drain and catch basin cleaning, as well as provide some standard definitions for the storm drain cleaning practice (Maguire).*



## Expert Panel Report on Street and Storm Drain Cleaning

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**Response:** Agreed. A new Section 4.7 has been added that summarizes storm drain cleaning research, and additional storm drain definitions have been added to Section 2. Tom Maguire provided draft text for both sections, which is shown in blue font in the revised expert panel report.

**Comment No. 6.** *Should the panel have applied a sediment delivery factor to reflect that not all street solids will ever reach the storm drain system? (MDE)*

**Response:** The expert panel strongly concurs that only a fraction of the street solids picked up by sweepers would ever reach the Chesapeake Bay, due to their large particle size. This is one of the reasons why the panel eliminated the hopper method for earning street cleaning credit (see also response to Comment 10).

The panel directly addressed the street solid delivery issue by using the WinSLAMM model to quantify the fraction of street solid mass that is actually conveyed from the street to the storm drain and ultimately discharged from the storm drain pipe. The documentation report prepared by Tetra Tech (2015) provides specific details on how the particle size of street solids was accounted in the simulation model. In general, the model simulates the particulate concentration for each storm event, based on the rainfall depth, runoff coefficient, street solid particle size distribution and street delivery factor for a defined street system.

Consequently, the WinSLAMM model provides a more fine-grained simulation of street solids and suspended sediment dynamics that occur in streets, gutters, storm drains and outfall pipes (and explains why the projected sediment removal rates associated with most street cleaning scenarios is so low).

The sediment loads that are discharged from storm drain pipes are still subject to the edge of field sediment delivery factor in the phase 5.3.2 CBWM. The panel references this in section 3.4 of the report (page 16).

It should be noted that not all of the sediment load generated from urban impervious cover actually reaches the Chesapeake Bay in the watershed model. 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).

The specific mechanics of how sediment delivery ratios are calculated may change in the next version of the CBWM (e.g., adding more impoundments and reservoirs), but these details go well beyond the charge of this expert panel report.

**Comment No. 7.** *Given the large particle size distribution for street solids, and the preferential pickup of large particles by sweepers, how does this square with the fine particle size (clay/silt) measured in the streams and rivers that flow to the Bay (MDE).*

## Expert Panel Report on Street and Storm Drain Cleaning

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**Response:** As noted the response to comment No. 6, the majority of medium and coarse-grained particles in street solids never reach the storm drain, stream network, or ultimately the Chesapeake Bay. The sediment reductions simulated by the WinSLAMM model primarily reflect the fine-grained particles that are observed at the river input monitoring stations further downstream (see also response to comment No. 10).

**Comment No. 8.** *Given the Figure 6 graphic showing poor pickup efficiency for regenerative air sweepers, why are they still considered an advanced cleaning technology ? (MDE)*

**Response:** MDE is correct when it notes that Figure 6 shows that regenerative air sweepers were not as effective as vacuum assisted sweepers in removing small sediment particles in the Selbig and Bannerman (2007) study. However, their study, as well as three other recent street cleaning studies, showed that regenerative air sweepers did have high sediment pick-up efficiencies which were generally comparable to those achieved by vacuum-assisted sweepers (Sorenson, 2013, SPU, 2009 and CSD, 2010). Consequently, the expert panel concluded that both qualify as Advanced Sweeper Technologies (AST) and thereby can earn higher pollutant removal rates than traditional mechanical broom sweepers.

**Comment No. 9.** *How did the panel evaluate street sweeping rates in the context of the role of downstream bank erosion in terms of the urban sediment load simulated by the Chesapeake Bay Watershed Model?*

**Response:** The panel acknowledges that downstream bank erosion is a major source of sediment loads in urban watersheds, as was established by the original Langland and Cronin (2003) report and validated more recently by a STAC research report (Sample et al, 2015). This important finding is implicitly addressed by the use of the Langland and Cronin curve relating urban sediment load to subwatershed impervious cover in the Version 5.3.2 CBWM (reproduced in Figure 1 of SR EP, 2013).

The USWG was recently updated on efforts to explicitly simulate how sediment loads might be allocated to upland areas versus the stream corridor in urban watersheds in the next version of the CBWM. The Center for Watershed Protection is testing several methods for doing so, and the decision to make any changes will be made by the Modeling Work Group, in conjunction with other stakeholders.

Predicting how these future modeling decisions will influence urban BMP removal rates (of any kind) is well beyond the scope of this or any other expert panel. The panel was not unduly concerned about how future modeling decisions might influence where urban sediment loads were generated, since they utilized an independent modeling approach to accurately define the upland sediment loads generated from streets.

## Expert Panel Report on Street and Storm Drain Cleaning

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### Section 3: Panel Recommendations on Credits and Verification

**Comment No. 10.** *Could the panel document why the 2011 hopper credit for street cleaning was eliminated, since many communities would still like to report it?*

**Response:** The expert panel considered the hopper credit, but elected to eliminate it for both scientific and operational reasons.

Part of the scientific rationale for dropping the hopper credit can be found in response to comment No. 6, which describes how the particle size distribution of street solids influences how they are delivered to the storm drain system. This is also evident in Table 7, which shows the typical particle size distribution of street solids, based on a national data review. As can be seen, 90% of all street solids are either medium-grained (75 to 1000 microns) or coarse-grained (more than 1000 microns). Only 10% of the street solid particles are fine-grained silts and clays that can become entrained in the stormwater runoff and move easily through the watershed.

The panel felt the new street cleaning credit based on the WinSLAMM modeling was greatly superior to the hopper credit, since it has a stronger technically and empirical foundation, explicitly accounts for street solids delivery, and provides municipalities with a greater range of street cleaning practices in which they can earn credit. By contrast, the old hopper credit method is prone to errors, especially if users do not fully understand the importance of all of its qualifying conditions (e.g., applies only to streets that have curb and gutters, are swept bi-weekly or more frequently by advanced street cleaning technologies).

From an operational standpoint, the panel concluded it was poor practice to continue to offer two methods to calculate credit for the same practice. The existence of two methods creates confusion and could become a major source of reporting problems and submission errors.

The panel did recommend a two-year grace period before the mass loading method for earning street cleaning credit should be phased out. Additional justification for the phase out of the hopper credit is provided in Section 6.3.

**Comment No. 11.** *PA DEP is hesitant to accept the panel's endorsement of a new transport land use in the Phase 6 CBWM without additional documentation on how it might influence future urban loads and BMP efficiencies in the Commonwealth.*

**Response:** Section 8.4 was eliminated from the final text. The actual authority to make land use changes to the CBWM (or, for that matter, any other changes to the CBWM), is reserved by other management entities within the Chesapeake Bay Partnership, and not individual expert panels. The decision to proceed with a new transport IC land uses in Phase 6 of the CBWM was made earlier this year by the Land Use Working Group, Modeling Work Group and Water Quality Goal Implementation Team.

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**Comment No. 12.** *PADEP does not support the panels proposed verification protocol involving a single annual sample for the street cleaning practice, as it too onerous and costly for small local governments to implement.*

**Response:** Verification is critical for annual operational practices such as street cleaning, since the degree of effort will change from year to year in response to budget resources, the size, age and technology of the local sweeper fleet and weather conditions.

The panel's street cleaning verification protocol (Section 7.2, page 47) recommends a single annual high quality sample of sweeper waste characteristics for each unique street cleaning practice (SCP) that is being claimed by the community. This verification approach was adopted in lieu of more stringent verification efforts that would involve measuring hopper loads or volumes after each daily street cleaning trip as originally suggested by some panel members.

The panel's verification protocol (a) provides greater transparency about what is actually being picked up off the streets within a community, (b) collects high quality data that can be shared among communities to further refine the street cleaning practice in the future and (c) requires limited resources in terms of costs for staff time and sweeper waste sampling.

Notes were added to the report to indicate that panel commendations on tracking and verification are advisory in nature, and are not binding on any state. Individual Bay states can provide alternate verification methods for street cleaning, as long as they satisfy the general verification principles agreed to by the Chesapeake Bay Program Partnership (CBP, 2014).

**Comment No. 13.** *Need to provide more technical support and sampling guidance on how to separate sediment from organic matter in the proposed verification method for the storm drain cleaning credit (e.g., sediment tends to stick to organic matter even when dried --Law).*

**Response:** The panel concurs that communities need more guidance on the sampling methods for the verification protocols for both street and storm draining cleaning, and has added some additional references. The panel recommended two initiatives to provide more technical guidance to help communities effectively implement the new credits. (Section 8.3, and excerpted below:)

- 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 verification samples.

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**Comment No. 14:** *Suggest changing "may" to "should" when it comes to the list of street cleaning record-keeping requirements provided on page 47, and require MS4s to report the total number of street miles that could potentially be swept in their community at least once every permit cycle (Wood, CBF).*

**Response:** In general, the reporting, tracking and verification recommendations developed by the expert panel are advisory in nature. The Watershed Technical Work Group is the final arbiter of what is required to be reported in Scenario Builder to get credit for pollutant reductions in the CBWM. Likewise, the state stormwater regulatory agencies are the ultimate authority on what records MS4 must retain to substantiate their local street cleaning effort.

While the panel agrees that communities should evaluate their entire street network when analyzing which combination of street cleaning practices could maximize pollutant reduction credits, they did not want to impose this as a local requirement or permit condition. The panel also observes that measuring the total street mileage in a community is easier said than done, given that actual street ownership is split between many different federal, state, local and/or private entities.

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