Technical Memorandum 1 - Literature Review

Research in Support of an Interim Pollutant Removal Rate for Street Sweeping and Storm Drain Cleanout Activities

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Final Draft

Summary of Street Sweeping Findings

- Although 75 monitoring and modeling studies were reviewed from the 1970s to present, fewer than a dozen studies provided sufficient data to quantify a pollutant removal rate for street sweeping.
- The ability to quantify pollutant removal rates based on the literature is challenging given the differences in scope, extent and design of field or modeling studies.
- The wide range of pollutant removal rates reported for street sweeping, vary based on sweeping frequency, sweeper technology and operation, street conditions, and the chemical and physical characteristics of street dirt.
- To overcome this problem, a conceptual model was developed to provide interim pollutant removal rates for TSS, TN and TP. The bounding conditions and assumptions were made based on the literature, and are reported in this memo.
- Although new street sweeping technology can remove more than 90% of street dirt under ideal conditions, it does not guarantee water quality improvements.
- Based on the conceptual model, the following interim removal rates are offered for urban streets swept according to the following sweeping frequency.

Interim pollutant removal rates from street sweeping for TSS, TP and TN.

Frequency	**TSS**	**TP**	**TN**
Monthly	16%	4 %	4 %
Twice a month	24%	5 %	6 %
Weekly	24%	5 %	6 %
Twice a Week	32%	8 %	9 %

Summary of Storm Drain and Catch Basin Cleanout Findings

- Only a handful of monitoring studies evaluate the pollutant reduction due to storm drain or catch basin cleanouts, and the optimal frequencies for cleanouts at a catchment scale.
- These studies indicate catchment cleanouts can reduce pollutants by 5 to 25% depending on catchment conditions, cleaning frequency and type of pollutant.
- The pollutant removal capability of catch basins is fundamentally constrained by the design which retains coarse grained sediments but bypass finer grained sediment that contain higher loads of nutrients and metals.
- A set of assumptions and bounding conditions were applied to the conceptual model based on limited data available from the literature. The pollutant removal efficiencies apply to catch basins that have not attained its 50% storage capacity. The removal rates decrease by about 50% if the storage in the catch basin is more than 50% of capacity.

Interim pollutant removal rates (%) from catch basin cleanouts for TSS, TP and TN.

Frequency	**TSS**	**TP**	**TN**
Annual	29	1	5
Semi-annual	56	2	10

The technical memorandum summarizes the available literature on municipal street sweeping and storm drain cleanout practices to help define interim pollutant removal rates for use in the Chesapeake Bay model. The literature search focuses on primary research studies from the 1970s to present that evaluate the capability of street sweeping and storm drain cleanouts to remove nutrients and other pollutants. In addition, the memo characterizes pollutant composition and particle size distribution of sediments in roads, curbs and catch basins. The survey period roughly coincides with the first Nationwide Urban Runoff Project (NURP) studies on sweeper effectiveness.

The literature review provides a sufficient basis to define interim pollutant removal rates for total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP) from street sweeping and catch basin cleanouts. Additional information generated from the municipal practices survey will help further define the interim pollutant removal rate that will be presented in the final report. The final removal rates will be adjusted to reflect additional monitoring data collected at experimental sites in Baltimore City and Baltimore County.

The technical memorandum is organized by eight major sections, which are summarized below.

1. **Background and History of Street Sweeping** - This section presents a brief overview of the street sweeping research from the NURP studies in the late 1970s and early 1980s to more recent studies. The background section highlights the shift in research methods to study the effectiveness of street sweeping and how it may affect water quality.

2. **Conceptual Model to Define Pollutant Removal Rate –** This section outlines a conceptual model that organizes the existing research to help define interim pollutant removal rates for select nutrients on street sweeping and storm drain cleanout practices.

3. **Characterization of Street Dirt** – Streets are one of many source areas for pollutants within urban watersheds. This section summarizes key characteristics of street dirt/particulate matter with a focus on sediments, nutrients and metals. The section reviews the sources and accumulation rates of street dirt and its physical and chemical characterization.

4. **Characterization of Storm Drain Inlet Behavior –** This section summarizes the quality of trapped sediment in storm drain inlets and catch basins, and reviews the physical and chemical characteristics of trapped material.

5. **Street Sweeper Performance –**This section summarizes the key factors that affects overall street sweeper performance, and evaluates pollutant removal for street sweeping based on sweeping frequency, technology and sweeping conditions.

6. **Storm Drain Cleanout Performance –** This section reviews the available research on the potential for storm drain and catch basin cleanouts to reduce stormwater pollutants.

7. **Interim Pollutant Removal Efficiencies –** This section outlines the detailed assumptions to derive pollutant removal rates for TSS, TN and TP over a range of street sweeping frequencies and catch basin cleanouts.

8. **Application of Project Monitoring Effort -** This section illustrates how monitoring data from this research project will be used to adjust the interim removal rates to derive final values. The section indicates how stormwater monitoring data in test catchments and sampling of street dirt and catch basins will be applied to the conceptual model to provide more accurate pollutant removal rates.

1. Background and History of Street Sweeping

The first major monitoring studies on street sweeping effectiveness were last completed in the late 1970s and early 1980s under the Nationwide Urban Runoff Project (NURP) (e.g., Pitt 1979, Pitt 1985, Bender and Terstriep 1984, Hansen and Sesing 1984). More recent street sweeping studies have a more narrow project focus and limited geographic scope (e.g., Brinkmann and Tobin 2001, Chang et al. 2005), or have used mathematical models to estimate sweeper effectiveness (e.g. Sutherland and Jelen 1995, Zarriello et al. 2002). Limited research has been done to evaluate the impact storm drain cleanout or the combined impacts on stormwater quality when street sweeping and catch basin cleanouts are done simultaneously (Mineart and Singh 1994, Pitt 1985).

The NURP research evaluated the effectiveness of mechanical street sweeping as a best management practice, and concluded that while street sweeping was effective at removing litter and larger particles, it produced no statistically significant reduction in nutrient concentrations in stormwater runoff (Pitt 1979). Although several NURP studies reported an overall reduction in total street dirt load due to the removal of larger particles (e.g. > 250 mm), pollutant concentrations tended to associate with the fine-grained sediments that were not as effectively removed by mechanical street sweepers (Sartor and Boyd 1972, Pitt 1979, Pitt 1985).

Over the past 20 years, advances in sweeping technology have focused on improving the removal efficiencies of fine-grained particles. Innovations in street sweeping technology and a broader awareness of stormwater pollution have led to a renewed interest in street sweeping. For example, modeling by Sutherland and Jelen (1997) found that small-micron surface cleaning technology could remove street dust by up to 70% for particles less than 63 microns (μm) compared to 20% for particles less than 104 μm using mechanical sweepers (Sartor and Boyd 1972). The small micron street cleaning technology is designed to pick-up street dirt as fine as 2.5 to 10 μm. Despite technological advancements, past research suggests that many factors such as sweeping frequency, street conditions, among others, limit or constrain the ideal pollutant removal rate that may be achieved by street sweepers.

Table 1 summarizes the major studies evaluating the effectiveness of street sweeping. The six major historical monitoring studies on street sweeping include Pitt (1979) who studied the pollutant removal effectiveness of three street sweepers under good and poor road conditions in San Jose, CA and five NURP studies that were located in Castro Valley, CA, Milwaukee, WI, Winston Salem, NC, Champaign, IL and Bellevue, WA (Pitt 1981, WI DNR 1983, NC DNRCM 1983, Bender and Terstiep 1984, Pitt 1985). Pitt (1979) developed the standard sampling procedures to test street sweeping equipment in the field. These sampling procedures were used at all five NURP sites, and have been employed by nearly every field monitoring study since. The NURP studies primarily examined residential streets, although some commercial and institutional streets were sampled. Bender and Terstriep (1984) reported that street sweeping was effective in reducing total street dirt loads on streets in Champaign, Illinois but found that particles smaller than 250 μm in size were less affected by street sweeping than the total load.

Table 1. Summary of major street sweeping studies. *

Study	Type of study	Location and Land Use	Type of Sweeper
Sartor et al. (1972)	Monitoring	Collected contaminant materials from street surfaces throughout United States.	Mechanical
Pitt (1979)	Monitoring	San Jose, CA Urban: good and poor asphalt	- Mechanical sweeper, - State-of-Art mechanical sweeper - Vacuum assisted sweeper.
Pitt (1981)	Monitoring	Castro Valley, CA	Mechanical
Hansen and Sesing (1983)	Monitoring	Milwaukee, WI	Mechanical
NC Dept Env & Nat Res (1983)	Monitoring	Winston Salem, NC: Residential and central business district	Mechanical
IL DENR 1982	Monitoring	Champaign, IL: Urban Drainage Basins: Residential, and Commercial	Mechanical Brush Sweeper
Sartor and Gaboury (1984)	Statistical model		Mechanical
Pitt and Bissonnett (1984)	Monitoring	Bellevue, WA: Residential/ suburban	Mechanical Regenerative Air
NVPDC (1996)	Modeling	Occoquan Watershed, VA	Mechanical

Sutherland and Jelen (1995)	Modeling	Portland, OR: residential, commericial, industrial, and transportation	Mechanicial, heavy flush following mechanical, and tandem – Vacuum assisted following mechanical
Sutherland and Jelen (1997)	Modeling	Portland, OR: Residential and Major Arterials	NURP Mechanical, Newer Mecahnical, Tandem Sweeping, Regenerative Air, Mechanical with vacuum assist
Waschbusch et al. (1999)	Monitoring and Modeling	Madison, WI: Residential	This was a source area study. Street sweeping was not a part of this study but street dirt was characterized.
Brinkmann and Tobin (2001)	Monitoring	Tampa, FL: 4 small urban watersheds ('99-00)	Mechanical Brush Sweeper
Waschbusch (2003)	Monitoring	Milwaukee, WI Highway	Mechanical with vacuum assist
Zarriello et al (2002)	Modeling	Lower Charles River, MA: Mostly Residential	Mechanical, Wet Vac, Regen. Air, Dry Assisted, Best Available Tech.
Kuhns et al. (2003)	Monitoring	Treasure Valley, ID	Vacuum Sweeper, Mechanical Broom Sweeper
Chang et al. (2005)	Monitoring	Tapei County, Taiwan	Modified Regenerative-Air Vacuum Sweeper followed by a Washer
Selbig (ongoing)	Monitoring and Modeling	Madison, WI	Vacuum

** This table does not represent all street sweeping studies but provides examples of the type of major studies completed or underway over the past twenty years and provide quantitative data to support the Conceptual Model present later in this report.*

This finding is significant because other research have reported that pollutants are not uniformly distributed among street dirt, but are found in higher concentrations in the fine-grained fraction of street dirt. Consequently, there are statistically insignificant improvements in the event mean concentrations of TSS, lead, iron, phosphorus, COD, and TKN for swept and unswept conditions. In conclusion, Bender and Terstriep (1984) and other NURP studies concluded that street sweeping was not effective in reducing pollutant event mean concentrations in stormwater runoff.

Interest in street sweeping as a best management practice was renewed in the mid 1990s. Improvements in sweeping technology such as the development of vacuum sweepers and regenerative air sweepers have believed to improve the removal efficiencies of fine particulates (Sutherland and Jelen 1997). Further improvements in technology have been able to reduce total suspended particles (TSP) less than 10 micron (μm) (PM_{10}) to improve air quality (Chang et al 2005, Kuhns et al 2003). More recent street sweeping research has focused on sampling street dirt or stormwater to compare the effectiveness of different sweeper technologies and have had less of a field monitoring component compared to the NURP-era studies (e.g., Brinkman and Tobin 2001, Kuhns 2003). However, there is an intensive field monitoring and modeling street sweeping study underway in Madison, WI. (USGS 2005). Other researchers have also developed mathematical models to estimate street sweeper effectiveness and the potential impacts of street sweeping on stormwater quality (Sutherland and Jelen 1996, Sutherland and Jelen 1997, Zariello et al 2002). Overall, the mix of monitoring and modeling studies have yielded conflicting estimates of removal rates which have ranged from negative to ninety percent. The wide diversity on pollutant removal rates makes it impractical to derive a median removal rate from published studies.

2.0 Conceptual Model to Define Pollutant Removal Rate

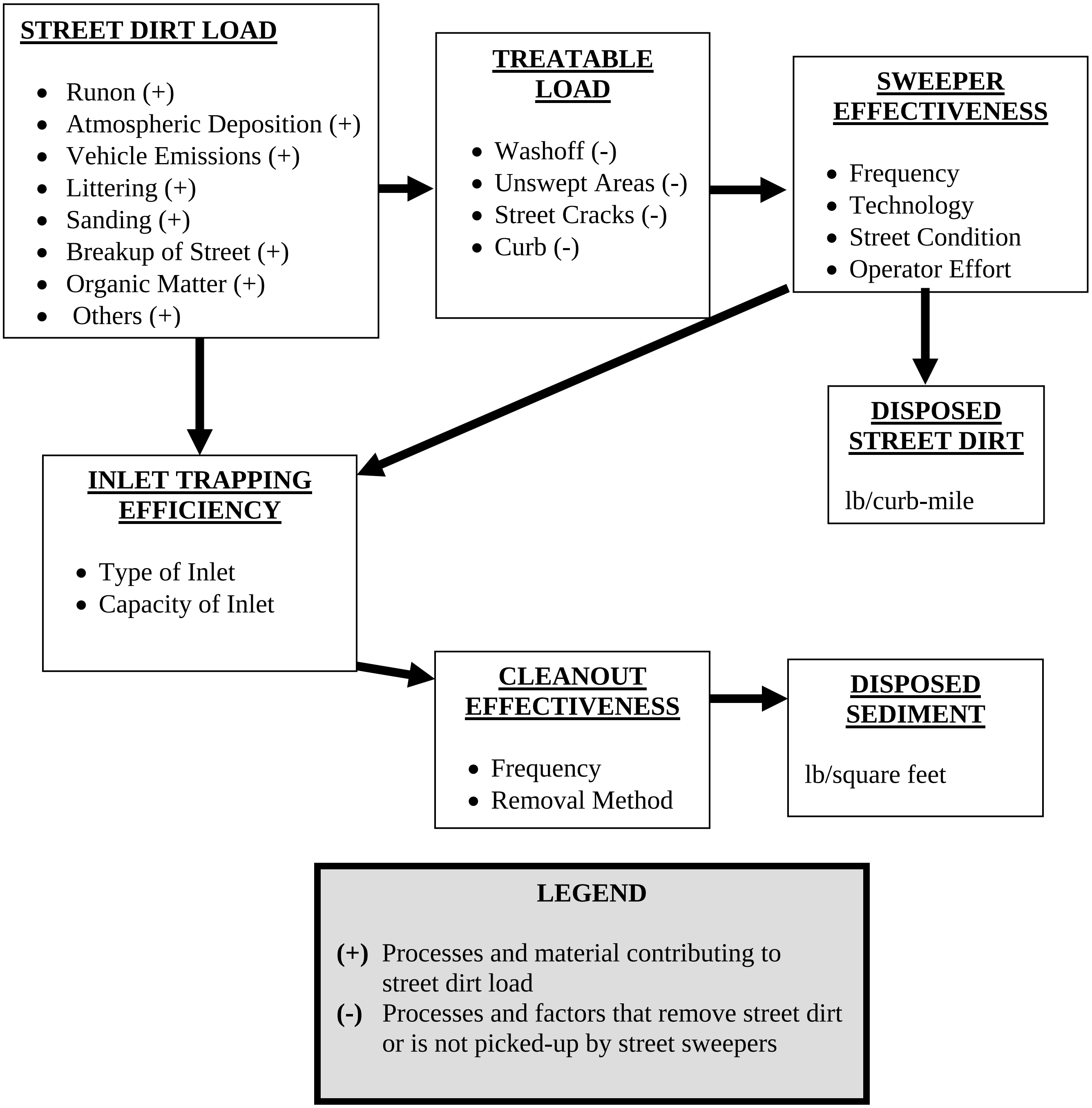
Although more than 75 studies and reports describe street sweeping performance, less than a dozen seminal papers provide data to evaluate the sediment removal rate by street sweeping and storm drain cleanouts. Even fewer studies provide reliable estimates on stormwater pollutant load reduction (Bannerman, 2006, Waschbusch 2003, Zariello et al., 2002, Mineart and Singh 1994, Pitt 1985). As such, it is impractical to take an average or median of the reported values. To overcome this problem, the Center for Watershed Protection developed a conceptual model to organize the existing research on street sweeping and storm drain cleanout practices to define an interim pollutant removal rate for TSS and nutrients (Figure 1).

A summary of existing urban storm water concentrations of sediment and nutrients from Phase I NPDES permit holders in the Chesapeake Bay Watershed are presented in Appendix A. These concentrations, taken with the interim pollutant removal rates for street sweeping and storm drain and catch basin cleanouts, suggest the degree to which these practices may reduce the nutrient loadings in stormwater runoff to the Chesapeake Bay.

2.1 Overview of Model

The conceptual model is defined by four components for both street sweeping and storm drain cleanout (Figure 1). *Street dirt load* is a model component that is shared by both practices. The street sweeping components are *treatable load, sweeper effectiveness* and *disposed street dirt*. The storm drain cleanout components include *inlet trapping efficiency, cleanout effectiveness* and *disposed sediment*. The conceptual model is further explained and applied in Section 7.0 to provide interim pollutant removal rates.

Figure 1. Conceptual model for defining removal rate.



Street Sweeping

Street sweeping studies do not typically quantify the specific sources of sediment and pollutants to the street, but past research indicates pollutants are delivered by: runon,atmospheric deposition, vehicle emissions, breakup of the street surface, littering, sanding, and others. It should be noted that runon from adjacent land uses often results in a net gain in street load (or negative effectiveness) as material washoff from streets during a storm event is replaced, or re-supplied, by erosion material (Pitt 1985). The street dirt load is approximated by using special vacuum techniques of several street-curb segments as described by Burton and Pitt (2001). Only a portion of the street dirt load can be removed by a street sweeper and is referred to as the treatable load. The treatable load is defined as the total street dirt load minus street dirt that is removed by washoff, trapped in street cracks, or located in areas that cannot be swept due to parked cars or other obstructions. In addition, the treatable load for nutrients is reduced to account for the dissolved or soluble nutrient fractions that are washed off during rain events. For example, Zariello et al. (2002) define an availability factor of eighty percent. The treatable load is then the amount of dirt that can be removed by the street sweeper.

Once the treatable load is defined, the load removed is determined by the street sweeper effectiveness. Sweeper effectiveness is controlled by four factors – sweeping frequency, sweeping technology, street condition and operator effectiveness. The amount of street dirt removed by a sweeper can then be quantified in units of mass per distance removed, such as lbs/curb-mile. This value, termed the disposed street dirt, is typically obtained from surveys of public works data on sweeper disposal.

Storm Drain Cleanout

Storm drains cleanout removal rates are not independent of street sweeping removal rates. In fact, many of the street sweeping components of the conceptual model also impact the storm drain cleanout components. For example, the total street dirt load and the amount of dirt removed by street sweeping both influence the quantity of dirt that can be trapped within storm drains, inlets, or catch basins. Inlet trapping efficiency is also a function of the type and design capacity of the inlet. In addition, trapping efficiency declines as the volume of trapped material reduces the inlet capacity. Storm drain cleanout effectiveness is impacted by both the frequency of, and method of cleanout. The amount of material removed from storm drains is quantified as mass per unit area, such as lbs/acres, and is called disposed sediment.

3.0 Characterization of Street Dirt

Sediment particles on the street, commonly called 'street dirt', are generally accepted as a major source of pollutants in stormwater (Sartor and Gaboury 1984, Pitt 1985, Waschbusch et al 1999). Street sweeping studies, such as those presented in Table 1, have analyzed street sediment and found measurable quantities of nutrients, metals, hydrocarbons, bacteria, pesticides, organochlorine and other toxic chemicals (e.g. PCBs and PAHs). Street dirt load is defined as the sediment or particulate matter found on the street surface (and any associated pollutants) that are washed off by a storm event of sufficient intensity (e.g. 0.1 inch/hr). In urban catchments, street dirt load is collected, stored, and conveyed to receiving waters through a network of streets, curbs, storm drains, and catch basins. Some of the street dirt load may be trapped and temporarily stored in storm drains until it is removed by either a large rainstorm or storm drain cleanout. Both the source and the particle size distribution of the sediment can affect the loading rate of pollutants on streets and in storm drains.

3.1 Sources and Accumulation of Street Dirt

Street surfaces are significant areas of accumulation for sediment, nutrient and metals. Typically, most of the accumulation occurs within 6 to 12 inches of the curb, but may vary based on street texture, condition and parked cars (Pitt 1979). Streets are the major source of suspended solids in urban runoff, contributing about 70 to 80 percent of the total load and 20 to 32 percent of nitrogen and phosphorus load (Pitt, 1985, Waschbusch, 1999, City of Baltimore 2003). Not only are streets major sources, but the concentration of suspended solids, bacteria and heavy metals can be four to eight times higher than other urban source areas such as lawns, rooftops, driveways and parking areas (Bannerman et al. 2003).

There are many pollution sources within a catchment that contribute to the street dirt load to include: runon from adjacent land areas, atmospheric deposition, vehicle emissions and wear, littering, sanding, deterioration of the street surface and erosion. The combined material generated from these sources may be defined as the total street load, and often contains sediment, paper and plastic litter, glass, and vegetation. The composition of street dirt is a product of many factors and conditions that vary locally (Pitt 1979) and therefore the amount that each source contributes to the total street dirt load can vary greatly from site to site.

A typical deposition rate of street dirt is 1,000 lb/curb-mile/day, but can range from about 100 to 2,000 lbs/curb mile/day, where higher street dirt loads are generally associated with streets in poor condition or in the spring as a result of winter road sanding practices (Sartor and Gaboury 1984, Pitt 1985, Bannerman 2006). In general, the amount of street dirt depends largely upon the length of time since the last cleaning, either by sweeping or washoff (Sartor and Boyd 1972). With time, however, the increase in fugitive dust losses as the street dirt load increases results in a slower accumulation rate of street dirt (Figure 2).

The accumulation rate is defined as the amount of material deposited, less the amount of material removed by street sweeping, washoff, traffic-induced turbulence or wind. A conceptual model to illustrate that pattern of accumulation and removal by rain and sweeping is shown in Figure 3. Accumulation rates vary largely based on parameter and particle size class for a range of land uses and street conditions and is greatest immediately after sweeping or washoff (Pitt 1979, NC DNRCD 1983). Table 2 provides some example accumulation rates for total solids and nutrients.

Figure 2. Deposition and accumulation of street dirt (Pitt et al. 1999).

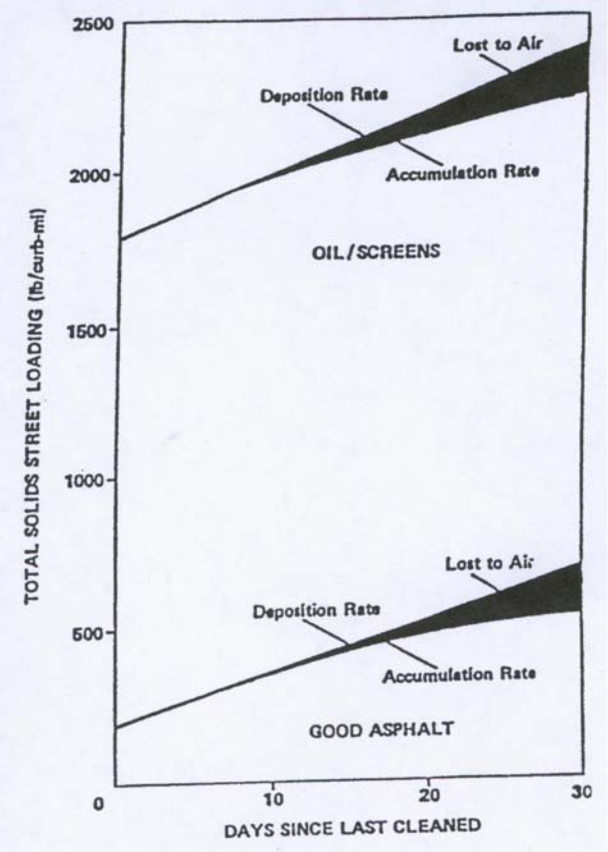


Figure 3. Conceptual model of street dirt accumulation and removal (from Sartor and Gaboury 1984).

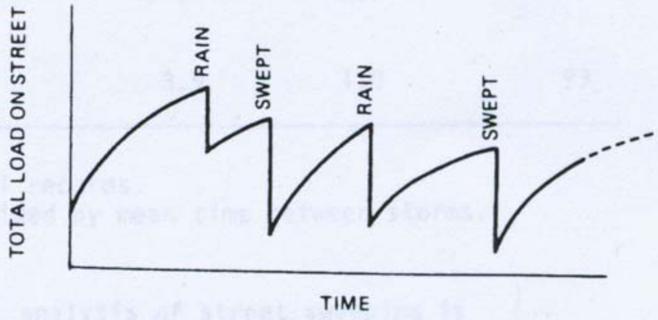


Table 2. Example daily accumulation rates for street dirt (lbs/curb-mile/day).

Study	Total street load
Pitt 1985	3.6 -21.3
Terstriep et al. 1982[1]	15.3 -70.7
WI DNR 1983	-0.2 -12.25
Pitt 1979	TSS: 9-21 TKN: 0.02 – 0.05 Dissolved P[2]: 0.01 -0.003 [3]

[1] Estimate based on maximum load divided by days to maximum load. This is not the reported deposition rate, that is higher for both land uses.
[2] as ortho-phosphate
[3] Estimated from annual deposition rates

A description of the factors that may affect the amount and quality of street dirt are summarized below.

Adjacent Land use- Adjacent land use may cause variations in the accumulation rate of sediment and associated pollutants. For example, accumulation rates for a heavily traveled commercial street were two to three times greater than for high density residential streets (WI DNR 1983). Streets in industrial areas generally appear to accumulate pollutants faster than commercial or residential areas (Sartor et al. 1974, Brinkmann and Toben 2001).

Runon - Runon from adjacent pervious areas become a significant pollutant source when rainfall exceeds 0.1 inches/hr (2.5mm/hr). The erosion of local soils can be a result of rain or wind, and is typically one of the largest sources of street surface particulates (Sartor and Boyd 1972, Pitt 1979). In areas where soil erosion is a major source of street dirt, the composition of street dirt reflects local geology. For example, in Florida where sandy soil is common, much of the street dirt is coarse grained (Brinkmann and Tobin 2001). This is also the case in cold weather regions where the use of sand applied for traction contributes to a more coarse grained distribution of street dirt. If construction sites are active in the catchment, they can generate street dirt (Waschbush 2003). Waschbush et al. (1999) and others have shown that nutrients and other pollutants are washed off by adjacent lawns at high concentrations.

Vehicle Emissions - The street dirt load originating directly from vehicle emissions and wear generally contributes only a small percentage of the total load (by weight), but these fine sediments are often be highly enriched with pollutants and can often be very toxic (Sartor and Boyd 1972, Pitt et al. 1997). The normal operation and wear of vehicles can be responsible for significant amounts of pollutants in street dirt, particularly for metals. For example, monitoring in the San Francisco Bay area revealed that wear and tear of vehicles contributed more than half of the copper, cadmium, and zinc entering the Bay (Santa Clara Valley Nonpoint Source Control Program 1992).

Street Condition - The contribution of street dirt and pollutants generated by the deterioration of the street surface strongly depends on the texture and condition of the road. Pitt (1979) found that differences in street texture and condition affected street dirt accumulation rates to a greater degree than the type of sweeper technology. One study found street dirt loads on rough streets were three to four times greater than smooth streets, and rough streets had a smaller percentage of particles less than 250 μm than smooth streets (WI DNR 1983). Pitt (1979) reported accumulation rates after street sweeping were two times greater for asphalt streets in poor condition compared to good condition (i.e., 10 lb/curb-mile/day for good condition and 20 lb/curb-mile/day for poor condition).

Atmospheric Deposition - Atmospheric deposition may be a significant source of street dirt loading that varies by land use and season (Schueler 1983, WI DNR 1983). Atmospheric pollutant loading rates in the metropolitan Washington, D.C. area have been estimated to be 243.3 lbs/acre/year for TSS, 17.0 lbs/acre/year for TN and 0.84 lbs/acre/year for TP (Schueler 1983). Given that streets are highly impervious, atmospheric deposition may contribute up to 95% and 35% of the total nitrogen and phosphorus stormwater load, respectively. The majority of the sediment deposition is associated with dry deposition whereas the TN and TP deposition rates is split between wetfall and dryfall. In North Carolina, nutrients were most often found in wetfall samples (NC DNRCD 1983).

Other - In some regions of the United States, anti-skid compounds such as salts (NaCl and $CaCl_2$), sand, and ash are frequently applied to roadways to melt ice and increase traction during cold weather. Aside from adding to the total street load, fluctuating concentrations of NaCl entering receiving waters can have detrimental effects on the local ecosystems (Hvitvet-Jacobsen and Yousef 1991) and can increase the long-term salinity of streams (Kaushal et al., 2005). The accumulation of chloride or other anti-skid materials on streets is likely traffic-dependent because the application of these compounds is focused on well-traveled streets (Pitt 1979).

3.2 Physical characterization of street dirt

The effectiveness of street sweeping may be related to the particle size distribution of street dirt given the association of specific pollutants with larger or smaller particle size classes. Studies typically partition the street dirt load into particle size classes for physical and chemical analyses, but the range of particle size classes often differ widely among studies. A consolidation of the particle size distribution presented in street sweeping studies is presented in Table 3. It should be noted that some of these values are estimates based on graphical interpretation of data. These analyses have shown the fraction of pollutant (by total weight) varies by particle size where nutrients are typically associated

Table 3. Street dirt particle size distribution of solids, percentage by total weight.

Reference	<63 µm	63-250	251 – 1,000	>1,000µm	Comments
Sartor and Boyd (1972)	7.9[a]	6.8[b]	20.4[c]	64.9[d]	Milwaukee
	25.9	35.8	20.9	17.4	Bucyrus
	18.0	31.8	22.3	10.6	Baltimore
	8.1	39.6	30.9	25.4	Atlanta
	7.7	29.1	16.7	36.5	Tulsa
NC DNRCD (1983)	5[a]	35[e]	45[f]	15	CBD
	3	26	49	22	Residential
Terstriep et al. (1982)	5	14	39	42	Mattis North
	4	13	37	46	Mattis South
	5	16	38	41	John North
	6	16	35	43	John South
Pitt and Bissonnette (1984)	9	20.5	31	45.5	No curbs
	2.5	8.5	33	56	No curbs
	9.5	25	41.5	24	Surrey Downs
	11.5	27.5	37.5	23.5	Lake Hills
Waschbusch et al. 1999	8	17	75[c]		
Waschbusch 2003	9	20.5	43.7	26.8	

[a] <43 µm, [b] 43 – 246 µm, [c] 246-840 µm, [d] > 840, [e] 45-212 µm, [f] 212 -1000µm

with the smaller-size fractions. Site specific differences in the particle size distribution of street dirt may be due to a number of factors including: local geology, street surface conditions, source, land use type, and activities such as deicing materials. For example, in drier climates of the Southwest a greater percentage of street dirt is found in the larger particle size classes, or the Midwest from the use of sand as an anti-skid compound (Sartor and Boyd 1972). Further, median particle size is greater for streets in poor condition or following a rain event (Pitt 1979, Pitt 1984). Seasonality may also affect the distribution of street dirt on residential streets where the majority of street dirt is found in the middle of the street in early Spring and along the curb in late Spring (Bannerman, 2006).

3.3 Chemical characterization

This section characterizes the concentration of nutrients and trace metals in street dirt as a function of particle size. With respect to the particle size classes of street dirt, the fine fraction of street dirt is often defined as particles smaller than 250 µm in size. Overall, it has been found that nutrients and metals are not evenly distributed amongst the particle size classes.

Nutrients

Concentrations of nitrogen and phosphorus in street dirt are generally greatest in the fine particle size fractions (i.e, less than 250 µm) but can vary from site to site. For example, Sartor and Boyd (1972) found that 92% of dissolved P was associated with particles less than 246 µm, whereas Waschbusch et al. (1999) found that approximately 80% of the TP was found in particles greater than 250 µm (Tables 4 and 5). The difference may be due to the leaf particles that were analyzed as part of the Waschbusch et al. (1999) study. Higher phosphorus levels were also associated with larger particle sizes in residential areas, compared with commercial sites where the concentration of phosphorus was more evenly distributed amongst particle size classes (Terstriep et al. 1982).

Despite the fact that fine particles have a relatively small contribution by weight, the corresponding nutrient load can be significant. For example, particles less than 43µm composed only 6 % of the total street dirt load, but were associated with more than 50% of dissolved phosphorus, 30% of the nitrate and about 20% of the TKN (Sartor and Boyd 1972). Similarly, Shaheen (1975) found that particles less than 75 µm comprised about 15% of the TKN and 25% of the nitrate nitrogen of the street dirt load in the Washington, D.C. area. Table 6 summarizes the average concentration of nitrogen compounds for street dirt sampled in the Washington, D.C. area.

Land use may also contribute to the enrichment of street dirt. Sartor and Boyd (1972) found industrial streets had TKN and dissolved phosphorus loads two to three times higher than residential streets, which were in turn 2 to 3 times higher than commercial sites. Nitrate loads were found in equal amounts at industrial and commercial streets, but were three times higher in residential streets (Sartor and Boyd 1972). Areas with tree canopy may have greater phosphorus in street particulate matter from leaf fall (Waschbusch et al. 1999, WI DNR 1983). For example, approximately 25 percent of phosphorus was contributed by leaf matter (Waschbusch et al. 1999).

Table 4. Percent (by weight) of pollutant associations with particle size fractions (from Sartor and Boyd 1972).

	Fraction of Total (% by Weight)		
Pollutant	**<43 µm**	**43-246 µm**	**>246 µm**
Total Solids	5.9	37.5	56.5
Phosphate-P	56.2	36.0	7.8
Nitrate-N	31.9	45.1	23.0
TKN	18.7	39.8	41.5
Trace Metals	51.2		48.7

Table 5. Percent of pollutants (by mass) in street dirt found in Madison, WI (Waschbusch et al. 1999).

	< 63 µm	**63-250 µm**	**>250 µm**	**Leaves**
Sediment	2.5	15.5	74	8
TP	5	15	50	30

[1] These values are approximately based on graphical interpretation.

Table 6. Average concentration of nitrogen in street dirt (from Shaheen 1975).

Particle size (µm)	<75 µm	75-250 µm	>250 µm
Nitrate-N	24.2	35.7	40.1
TKN	14.8	45.4	59.8

Metals

Trace metals found in street dirt are largely attributed to automobile emissions and wear and commonly include: lead, iron, zinc, calcium, cadmium, chromium, copper, mercury, nickel, and manganese (Sartor and Boyd 1972, Shaheen 1975, Wilbur et al 1979, Fergusson and Ryan 1983). Of these elements, lead, zinc and iron are the most prevalent in street dirt and lead is the most frequently studied (Sartor and Gaboury 1984, Hvitved-Jacobson and Yousef 1991). Trace metals are strongly associated with the finer size fractions street dirt, and concentrations generally increase with decreasing particle size (Shaheen 1975, Fergusson and Ryan 1984, Hvitved-Jacobsen and Yousef 1991, Schorer 1997) (Table 7). This may not always be the case as concentrations of trace metals in street dirt can vary widely from site to site with respect to street condition and land use. Higher concentrations of metals are found at commercial streets compared to residential streets, and streets in poor compared to good condition (Pitt, 1979)(Terstriep et al. 1982).

Table 7. Percent (by weight) of heavy metal pollutants associated with fine particles (less than 250µm).

Pollutant	Percent
Lead	62.3[a]
Zinc	54.1[a]
Trace Metals	51.2[b]

[a] Data from Shaheen (1975) for particles <250µm

[b] Data from Sartor and Boyd (1972) for particles < 246µm

4.0 Characterization of Storm Drain Inlet and Catch Basin Behavior

Few studies have characterized the particle size of sediment within storm drain inlets and catch basins. Direct comparison between the few studies is difficult given differences in accumulation rates and the type of material sampled (wet, dry, total). A distinction is made between catch basins and inlets, where catch basins have a sediment sump at the base of the well or chamber to retain material whereas an inlet does not.

Sources and accumulation

Accumulation studies show that the amount of polluted sediment in the storm drainage system (inlets and catch basins) is about twice the amount on the streets at any given time (Pitt 1985). Measured catch basin accumulation rates in swept catchments are about 40-80 lb/acre/yr in residential catchments where the higher rate is due to catch basins located on, or just downstream from, uncurbed streets with significant off-street sediment sources (Pitt 1985). In the same study, inlet accumulation rates were about half of catch basins ranging from 24-32 lb/acre/yr. Higher accumulation rates were observed in Australia, ranging from 38 to 118 lbs/acres/yr for inlets in swept residential, industrial and mixed land use catchments (Walker and Wong 1999).

An example of the type of material sampled in inlets is given in Table 9. Mineart and Singh (1994) found inlets within different land uses, monitored in California have a similar proportion of trash, leaves and wood (Mineart and Singh 1994). The inlets at the industrial land use sites had up to fifteen times more oil/sheen material and up to twenty-one times more inlets with a rotten egg smell. For comparative purposes, material accumulation in oil-grit separators from recent storm events was similar to industrial land use storm drain inlets. That is, up to fifty-five percent of the material is classified as wet and is similar to findings by Schueler and Shepp (1993) for oil-grit separators.

Table 9. Summary of storm inlet debris characteristics (reported as percent of inlets with indicated characteristics) (from Mineart and Singh 1994).

Characteristic	Residential (%)	Commercial (%)	Industrial (%)
Wet	30	26	55
Trash	60	63	52
Soils	34	48	69
Leaves and Wood	63	75	67
Organic Material	32	28	59
Rotten Egg Smell	4	1	21
Illegal Discharges	2	5	1
Oil/Sheen	4	1	15

Physical characteristics of catch basin sediment

The quality of the sediments trapped in catch basins is dominated by coarse-grained particles. The sediment wet-fraction of catch basin contents is estimated using data from Sartor and Boyd (1972) street dirt loads, where a multiplier of 1.0 for total solids and trace metals and a multiplier of 0.5 for organics and nutrients is used to convert from dry street dirt pollutant loads to wet catch basin sediment (Table 10). Pitt and Bissonnett (1984) found similar quality of catch basin sediment across particle size classes compared to the chemical composition of street dirt particles (see Table 12). Although, the catch basins sediment particle size distribution has a larger proportion of fine particles compared to street dirt (Pitt 1985).

Table 10. Fraction of pollutants by particle size fraction of catch basin sediment (from Lager et al. 1979).

Parameter	**<43**	**43-246**	**246-2,000**	**>2,000**
Total solids[a]	5.9	37.5	32.2	24.4
Volatile solids[b]	12.8	17	14.7	5.5
TKN[b]	9.4	19.8	15.8	5
Nitrate-N[b]	15.9	22.6	8.3	4.3
Phosphate-P[b]	28.1	18.0	4.0	0
Trace metals[a]	27.8		32.4	16.3

[a] The total fraction will equal 100% based on the multiplier effect

[b] The total fraction will equal 50% based on the multiplier effect.

Nutrients

Catch basins can temporarily enrich the concentration of runoff if stored within the catch basin and flushed out during a storm. For example, Lager et al. (1979) found that liquid samples from a catch basin for BOD_5 may reach concentrations 7.5 times greater than runoff if the sediment stored in catch basins had been in contact with street litter. An indication of the level of nutrient concentrations that may be found in catch basins is provided in Table 11. It is expected that total nitrogen (TN) concentrations are much higher in the liquid media than total phosphorus given the differences in their physiochemical characteristics (e.g. solubility).

A significant amount of pollutant load is associated with the sediment fraction as suggested by the high levels of nutrients found in catch basins (Table 12). For comparative purposes, the sediment found in catchbasins is similar in quality to that found in oil-grit separators located on streets and in a residential area (Table 13). A high percentage of the total mass was volatile solids for all of the land uses studied (Schueler and Shepp 1993).

Table 11. Pollutant concentrations (mg/L) in the liquid fraction of catch basins[a] and water column[b] of oil grit separators.

Parameter	**Catch basin** [a]	**Townhouse Garden apartments**[b]	**Streets**[b]
TN	8	▨	▨
TKN	▨	1.0	0.84
NH_3-N	▨	0.2	0.19
TP	0.2	0.19	0.06

[a] Lager et al. 1979 from a study in SanFransisco

[b] Schueler and Shepp (1993)

Table 12. Average sediment concentrations (mg/kg) in catch basins in Bellevue, WA (Pitt and Bissonnette 1984)

Particle size (μm)	**TKN**	**TP**	**Pb**	**Zn**
< 63	2,900	880	1,200	400
63-125	2,100	690	870	320
125-250	1,500	630	620	200
250 -500	1,600	610	560	200
500-1000	1,600	550	540	200
1000-2000	2,600	930	540	230
2000-6350	2,400	1,100	480	190
>6350	2,100	760	290	150

Table 13. Residual sediment quality within oil grit separators (mg/kg) (Schueler and Shepp 1993).

Land use	**TKN**	**TP**	**TOC**	**HC**	**% Solids**	**% Volatile Solids**
Townhouse Garden Apts	1,760	266.7	32,392	894	55.7	8
Streets	1,719	365	33,025	3,482	40.7	12.9

Metals and Other Pollutants

The concentration of metals accumulation in catch basins is a function of particle size as catch basins are more efficient at capturing coarse-grained particles. As a result, the fine-grain particles with higher concentration of metals (and some nutrients) are not effectively reduced by catch basins (Lager et al. 1979). Lager et al. (1979) estimated that approximately 28% of the total heavy metals are associated with particles less than 246 μm (see Table 10). Mineart and Singh (1994) reported metal concentrations of sediment in storm drain inlets was lowest at the residential inlets, measuring about 30 to 50 percent lower than commercial and industrial sites (Table 14). The trace metal concentrations are similar for zinc but much higher levels are found for lead in Bellevue, WA catchbasins compared to samples in California by Mineart and Singh (1994) (Tables 12 and 14).

Petroleum hydrocarbons at residential catch basins were twice as high as the other two land uses categories, but are much higher than the concentration of hydrocarbons found in oil-grit separators of similar land use (i.e., townhouse). The majority of hydrocarbons in the inlet sediments could be traced to the products of combustion as opposed to direct petroleum spill (Mineart and Singh 1994).

Table 14. Storm Inlet Sediment Quality (median concentration in mg/kg) (From Mineart and Singh 1994).

Land Use Type	Copper	Lead	Zinc	Total Petroleum Hydrocarbons
Residential[a]	37.9	43.8	215	5000
Commercial[a]	56.7	111	597.5	2050
Industrial[a]	46.6	117	307	1950
Streets[b]	173	544	1,800	3,482
Townhouse[b]	162	180	878	894
Pond[b]	130	200	900	474

[a] Mineart and Singh (1994), mg/kg

[b] Schueler and Shepp (1993), μg/g , except for HC expressed as mg/kg

5.0 Street Sweeper Performance

Street sweeper performance is based on the street dirt pick-up efficiency by various technologies and how effective street sweeping is in reducing pollutant loads in stormwater. Monitoring and modeling-based research, to date, has demonstrated a wide range in pollutant removal efficiencies and load reductions that can be achieved by street sweeping. However, even an ideal street dirt pick-up rate that may exceed 90% by street sweepers does not necessarily guarantee water quality improvements given the many factors and processes that affect street sweeping pollutant removal rates. Street sweeping as an effective stormwater control practice is dependent on street sweeping frequency, sweeper technology and operation, street conditions and sources of pollutants in stormwater. Although few studies have shown how street dirt pick-up can influence stormwater quality, the potential to improve water quality by street sweeping is one of the top reasons for such practices (Schilling 2005).

5.1 Pollutant pick-up efficiencies by street sweeping

Research demonstrates a wide range of pollutant removal rates or load reductions that may be achieved by street sweeping. Typically, both monitoring and simulation-based studies illustrate street sweepers being more effective at removing larger-size particles than fine-grained particles, and poor at removing nutrients. However, despite the high street sweeping pick-up efficiencies, even under ideal conditions, few studies have shown statistically significant decreases in stormwater pollutants. For example, the City of Baltimore found significant decreases in most parameters including nitrogen, but not for phosphorus in stormwater following a study on street sweeper effectiveness (City of Baltimore 2003). Due to insufficient sample size and study period, the results were inconclusive with regard to the impact from street sweeping (City of Baltimore 2003). In another study, marginal statistically significant improvements in runoff quality were observed in Milwaukee, WI, but overall there was high variability in the results (Selbieg et al. 2003, Bannerman 2006).

Table 15 summarizes monitoring efforts by Sartor et al. (1974) that demonstrates an overall street sweeping pick-up efficiency of 50% for mechanical sweepers, but ranges from 15% for particles less than 43 μm and up to 79% for particles greater than 2,000 μm. The range in street sweeping pick-up efficiencies in modeling studies presented by Sutherland and Jelen (1997) and NVPDC (1996) show a similar overall efficiency of 51% but differ for the range in particle size classes (Tables 15 and 16). Newer technologies demonstrate greater pick-up efficiencies (Table 17) (Sutherland and Jelen 1997).

Table 15. Sweeper pick-up efficiency based on particle size.

Particle Size (μm)	Percent[a] (Monitoring)	Percent[b] (Model)
>2000	79	67
840-2000	66	
246-840	60	
104-246	48	34
43-104	20	
<43	15	15
Overall	50	50

[a] Sartor et al. (1974)
[b] NVPDC (1996) for total solids

Table 16. Street sweeper pick-up efficiencies for a range of particle size classes and pollutants (from NVPDC 1996).

Particle size	**Nitrates**	**Dissolved P**	**Trace Metals**	**BOD**
Particle Size (μm)	**Percent removal**			
≤ 43	5	8	n/a	4
43 -246	15	12	14	11
≥ 246	15	5	33	29
Overall (%)	**35**	**25**	**47**	**44**

Table 17. Model-based removal efficiencies for a range of particle size classes and technology (from Sutherland and Jelen 1997).[1]

Particle size	NURP-era mechanical	Newer Mechanical	Regenerative Air	Vacuum
µm	**% removal**			
<63	44	100	32	70
63 > 125	52	100	71	77
125 >250	47	92	94	84
250 > 600	50	57	100	88
600 >1000	55	48	100	90
1000 > 2000	60	59	100	91
>2000 µm	51	76	82	82

[1] The efficiencies represent removal greater than the base residual or street dirt in permanent storage.

Given the more efficient removal of larger sized-particles by street sweepers, field studies find that the median particle size of street dirt is lower following street sweeping (Pitt 1979, Bender and Terstriep 1984, Pitt 1985). The remaining finer-grained particles on the street may increase the pollutant loading risk to receiving waters given the ability for the smaller particles to be more readily washed off, and their general higher pollutant concentration relative to the larger particles. Therefore, the timing and frequency of street sweeping becomes a significant factor for the design and implementation of a street sweeping program.

Overall, research has demonstrated that street sweeping may reduce pollutants in stormwater by up to ten percent. For example, model simulations for the Lower Charles River, MA presented by Zarriello et al. (2002) suggest that street sweeping using high efficiency sweepers may achieve, at most, a 10% reduction of solids and total lead and less than 5% water quality improvement for fecal coliform bacteria and total phosphorus by twice a week sweeping or less. Similar improvements in water quality were found in the monitoring study by Pitt and Bissonnett (1984) where intensive street cleaning of residential streets 3 times/week would improve stormwater runoff by 6-7.25% in the catchment, depending on the technology used (Pitt 1985). These low efficiencies were in part, attributed to the local rainfall patterns, that was effective at removing street dirt during the study period. This is despite the fact that the majority of the heavy metals (e.g. Pb, Zn) and chemical oxygen demand (COD) were originating from street dirt.

5.2 Factors that Affect the Effectiveness of Street Sweeping

Monitoring studies have found the four major factors that affect street sweeping include: sweeping frequency, sweeper technology and operation, and sweeping conditions. In addition to these four factors, runon from adjacent land uses may negatively impact the effectiveness of street sweeping. A brief discussion of these factors is presented below.

Frequency

Street sweeper pick-up efficiency is heavily influenced by sweeping frequency and is cited as a factor more important than the technology used (Pitt 1979, Walker and Wong 1999). The street sweeping frequency should be defined based on local rainfall statistics, where the optimal frequency is about twice the interstorm period based on national rainfall statistics (i.e., approximately once a week), or up to two times a week for pick up of street dirt by up to 50% by mechanical sweepers (Sartor and Gaboury 1984). Less frequent sweeping increases the probability that the street dirt load would likely be washed-off into the storm drains by rain and snowmelt. Most researchers over the past twenty years indicate that weekly street sweeping for residential and some commercial streets is needed to maximize pick-up of the street dirt load (Sartor and Gaboury 1984, Bender and Terstriep 1984, Sutherland and Jelen 1997, Brinkmann and Tobin 2001). Table 18 summarizes a range of pollutant removal rates given a set of sweeping frequencies and street sweeper technology.

Table 18. Pollutant removal efficiencies of total solids for various street sweeper technologies given a range of sweeping frequencies.

Frequency	Old Mechanical	New Mechanical	Regenerative Air- vacuum	Vacuum	Overall range
Monthly/Bimonthly 10-20x/year	n/a	18[1]	42[1]	n/a	18-42
Biweekly	n/a	22[1]	52[1]	62[1]	22-62
Weekly	23[2a], 35[2b], 24[3a]	30[1]	65[1]	n/a	23-65
Twice a week	62[2a], 18.5[3b]	35[1]	49[4],72[1]	26.3[5a],42[5b]	18.5 -72

1 Sutherland and Jelen, 1997 modeling study, parameter not specified
2a Bender and Terstriep, 1984 monitoring study refers to total solids for residential areas
2b Bender and Terstriep, 1984, refers to total solids for commercial land use
3a WI DNR, 1983 monitoring residential land use, 1-2 times/week
3b WI DNR, 1983 commercial land use, 2-3 times/week
4 Pitt, 1985 monitoring based on average before and after street sweeping street dirt loads
5a NC DNRCM, 1983 monitoring refers to the total weight of street dirt from residential areas
5b NC DNRCM, 1983 refers to the total weight of street dirt from commercial land use

Technology

A description of three major types of street sweepers is provided in Table 19. The ability for street sweeping to impact stormwater water quality rests with its pick-up efficiency of significant amount of fine-grained sediment. The inability of street sweepers to improve stormwater quality in NURP-era and other studies is attributed, in part, to their inefficiency at removing the smaller particle size fraction of street dirt. Modeling studies suggest that newer street sweeping technologies are expected to provide greater reduction

Table 19. Major types of street sweepers available and key advantages and disadvantages. (from NVPDC 1996, Walker and Wong 1999)

Type	Advantages	Disadvantages
Mechanical	-relatively inexpensive -good at removing gross pollutants -easy to maintain	-not as effective at picking up finer-grained particles.
Regenerative-Air	-good at removing most gross pollutants -better at removing fine-grained sediment than mechanical sweepers. -can dislodge sediment from cracks.	-difficulty picking up heavy, coarse grained sediment. -difficulty picking up wet vegetation.
Combination or High-Efficiency	-good at removing gross pollutants. -best at removing fine-grained sediment. -can operate without water.	-most expensive. -difficulty picking up wet vegetation. -longer body, so may be less maneuverable.

in pollutant load, achieving up to 80% reductions in TSS in residential catchments (Sutherland and Jelen 1997). Sutherland and Jelen (1995, 1997) demonstrate through model simulations, under ideal sweeping conditions, that newer sweeping technologies have the ability to pick-up the fine-grained street dirt. This improvement in pick-up efficiency may not provide a significant improvement in water quality if local conditions and physical characteristics of the area are not considered. For example, Pitt and Bissonnett (1984) concluded that a regenerative-air sweeper could remove more of the finer street surface materials in residential basins compared to a mechanical sweeper but did not significantly improve urban runoff quality.

Sweeper Operation

Operation type, meaning single or tandem operation, and operation speed are two additional factors that can influence the effectiveness of street sweeping. Tandem operation means that two sweepers (any combination of different types) sweep the same route, with one following the other to pick up any material that was missed. Tandem sweeping had the greatest overall removal efficiency of 91% compared to mechanical, regenerative and vacuum assisted sweepers (Sutherland and Jelen 1997). The removal efficiency of sweeping can also be improved if the street sweeper makes multiple passes on a street, (Pitt 1979) and operates at the optimal operating speed for street sweepers, which is about 6 to 8 miles per hour (FHA 2000).

Street conditions

The ability of the street sweeper to access the curb is paramount to street sweeping efficiency as the majority of the pollutant on streets is closest to the curb, but may vary seasonally (Bannerman 2006). Parked cars on the streets restrict access to the curb and are the top ranked problem for street sweeping programs (APWA 1978). Communities have typically responded to the parking problem by imposing parking restrictions and enforcement. However, parking restrictions have a mixed effect on reducing the percent of total street surface loads (Pitt 1979). For example, parking regulations on smooth streets resulted in an increase of up to 24% total solids removal, whereas streets with extensive parking that had restricted parking during sweeping operations resulted in a 28 percent decrease in the amount of total solids removed. This decrease was attributed to parked cars that block street dirt migration to the curb and have higher loads of street dirt in the middle of the street.

Non-street dirt sources from runon

Pollutant sources within a catchment are many and may contribute to the total street dirt load during a rain event. As the total flow to a street section comes from the larger catchment area, runon may counter the effectiveness of street sweeping and result in a net gain of street dirt following a storm. WI DNR (1983) found that typically larger sized particles (e.g., > 125 μm) increased by nearly 50% after a rainfall. Residential lawns, driveways, parking lots and rooftops may provide significant contribution to nutrient and metals loadings to stormwater runoff (Bannerman et al 1993, Waschbusch et al. 1999, Pitt 1985). As a result these stormwater loads would bypass the street dirt system and essentially decrease the effectiveness of street sweeping efforts.

6.0 Storm Drain and Catchbasin Cleanout Performance

The sediment trapping efficiency of a catchbasin is its ability to retain the sediment material and not be washed out, or reach a threshold where blockages occur. Although storm drain inlets are not designed to retain sediment, material is stored between storm events. There are two studies on the performance of catchbasin and storm drain cleanouts as a Best Management Practice on a catchment scale by Pitt and Bissonnette (1984) and Mineart and Singh (1994). The in-depth study by Lager et al. (1979) combines field data with modeling design studies to determine the sediment trapping efficiencies of catch basin designs.

Frequency

The cleaning frequency should be defined such that blockage of the storm sewer outlet is prevented and it is recommended that the sump not exceed 40-50% of its capacity. Once catch basins reach this capacity, sediment trapping efficiencies decrease rapidly and may become negative (Lager et al. 1979, Pitt 1984). The factors that relate to an optimal cleanout frequency include: antecedent dry period, weather, adjacent land use, topography, erodability of soils, accumulated street solids and pump capacity (Lager et al. 1979). Most communities clean out their catch basins annually or in response to complaints from residents. Typical catchbasin cleanout frequency is annual, but may be as frequent as bimonthly for very few municipalities (Lager et al. 1979 from 1973 APWA survey). Semiannual cleanouts in residential streets and monthly cleanouts for industrial streets are suggested by Pitt and Bissonnett (1984) and Mineart and Singh (1994), respectively.

Technology

The four common methods of cleaning catch basins are described in Table 20, where vacuum combination jet cleaning is more prevalent in current practices.

Table 20. Equipment used for catch basin and inlet cleaning (from Lager et al. 1979)

Equipment	**Description**
Manual cleaning	Bail out sediment laden water and shovel into street then truck. Or crew enters catch basin and fill buckets with sediment that are then carried to a dump truck. Clean water is used to refill the catchbasin. Equipment needed includes: dump truck, clamshell shovel, scoop shovel, brooms, grating lifter, self-priming solids pump and hoist on truck
Eductor cleaning	Eductor truck evacuates the catchment of the sediment laden water into a settling tank. Equipment used: eductor truck, rake, scoop shovel, broom and grating lifter
Vacuum cleaning	Air blower of the vacuum truck is used to create a vacuum and the air-solid-liquid material is separated in the vacuum truck unit by gravity separation and baffles. Equipment used: Vacuum truck, extenstions for vacuum line, flushing water, pole for cleaning corners and grating lifter
Vacuum combination jet cleaning (e.g. Vaccon)	A vacuum assisted truck that uses a combination of air, water and hydraulic suction. Suction is used to extract material from storm inlets and water is used to clear material from storm drain pipes that is not removed by the vacuum. The material is stored in the truck holding tank and transported for disposal.

Sediment trapping efficiencies

The hydraulic function of a catch basin affects the settling properties of the sediment such that greater solid capture is related to lower flow through rates and turbulence (Lager et al 1979). Monitoring and model simulations of clean catch basins show that sediment trapping is lower for smaller particles sizes (< 250μm) and for higher flow rates (0.25 to 0.5 cfs) (Table 21). Trapping efficiencies less that 13% occurred for particles less than 100μm in size and in most cases passed through the catch basin entirely. This finding has important implications for water quality as a high proportion of nutrients are associated with smaller size fractions. Although sediment trapping efficiency is much higher for particles greater than 250μm, the majority of the nutrient load is associated smaller particles (see Table 10). In addition, Lager et al. (1979) found that catch basins become less effective when the accumulated depth exceeds 50-60% of its storage capacity (Lager et al. 1979)

Using the available monitoring data and modeled relationships, Lager et al. 1979 provides estimates of pollutant removal efficiencies for a range of cleanout frequencies assuming best conditions of the catch basins (Table 22). The best conditions are represented by a minimum flow rate of 0.25 cfs through basins that are empty. According to the model, sediment trapping efficiency approach 75% when storm drains are cleaned out on a semi-annual or annual basis (Lager et al. 1979). The minimum trapping efficiencies predicted by Lager et al. (1979) are much higher compared to those provided by Pitt and Bissonnett (1984). Pitt and Bissonnett (1984) found that cleaning inlets twice a year could achieve reductions of total solids in urban runoff by 10 to 25 percent and estimated that COD, nutrients, and zinc may be reduced by 5 to 10 percent. Mineart and Singh (1994) were more conservative in their findings for copper and found that monthly cleanout frequencies may reduce annual pollutant loadings by 3-4% and up to 12%, if illegally dumped pollutants were captured.

Table 21. Sediment trapping efficiencies for model and field observations for catchbasins (from Lager et al. 1977).

Particle size (μm)	Model flow rate of 0.25 cfs	Field observations[a] 0.28 cfs	Model flow rate of 0.5 cfs
<100	n/a	12.6	n/a
100 -250	68.6	51.1	45.2
250-840	97.5	82.3	91.5
840 -2,000	99.3	91.1	98.9

[a] Sartor and Boyd (1972)

Table 22. Sediment trapping efficiency (%) by catchbasins for a range of cleanout frequencies (from Lager et al. 1977).

Parameter	Every two years	Annual	2 to 4 times per year
Total solids	19.6	39.1	75
Volatile solids	6.6	13.3	25.5
TKN	7.1	14.3	27.4
Nitrate-N	4.4	8.9	17.1
Phosphate-P	1.6	3.1	6.0
Trace metals	16.8	33.6	64.4

7.0 Interim Pollutant Removal Efficiencies for TSS, TN and TP

To estimate pollutant removal rates for TSS, TN and TP for street sweeping and catch basin cleanouts, a set of bounding conditions and assumptions were made based on the literature review. A list of discount factors that reduce the pollutant removal rate of these practices are presented in Table 23. In some cases, assumptions had to be made in the absence of data or the lack of agreement among research findings. As one example, estimation of sediment trapping efficiency by cleanout method and type of inlet were not

Table 23. Discount factors that reduce the effectiveness or street dirt load for street sweeping and catch basin cleaning.

STREET SWEEPING	CATCH BASIN or STORM DRAIN INLET CLEANOUT
• Removal of particulate-phase pollutants • Washoff • Fugitive dust loss • Frequency of sweeping (e.g., less than weekly) • Equipment used/technology • Street conditions (e.g., good or poor condition, residual dirt load) • Access to curb (e.g., parked cars)	• Coarse vs fine-grain sediment • Cleanout frequency • % Catch basin/Inlet full (>50%) • Cleanout method

available. The interim pollutant removal efficiencies will be refined following analyses of survey data generated as part of this project and presented in Memo 2.

7.1 Street Sweeping Interim Pollutant Removal Rates

A hypothetical amount of 100 units of a type of pollutant is used to simplify the calculations to estimate the potential pollutant removal rate associated with street sweeping. The treatable load is first estimated as the street pollutants that are available to be picked up by a street sweeper. It is defined as the particulate fraction of total phosphorus or total nitrogen (e.g. TKN). The median stormwater concentration for each parameter for the Chesapeake Bay communities was taken from the National Stormwater Quality Database (NSQD). The relative impact of washoff, fugitive dust loss and parked cars are constants for the examples given, whereas the fraction of particulate and sweeper efficiencies are parameter specific. The values in italics are best professional judgement as the literature review provided sweeper efficiencies for a limited set of frequencies and parameters. The removal efficiencies used in the example are largely related to residential streets.

The major factors that remove street dirt include washoff of rain events greater than 0.1 inch/hr and fugitive dust loss. The washoff value is representative of street dirt washoff and does not include the additional street dirt contributed from runon. Runon would further discount the effectiveness of street sweeping. The condition of the street and access to curb due to parked cars further reduce the treatable load and vary by pollutant type. For this example, the street condition is assumed to be in good condition with moderate parking where the sweeper moves around parked cars as needed. There is also the base residual street dirt that remains and is not washed during most rain events or even picked up by the most efficient street sweeper. The base residual may only be mobilized during the most extreme or intense rainfall event. Zariello et al. (2002)

assigned an availability factor of eighty percent, indicating that twenty percent of the street dirt load would not be available for sweeping. However, the base residual would be a constant value for a street, rather than relative and would be very site specific so it is not applied to this example calculation. Particle size distribution will also affect street sweeper efficiency where larger particles will have a higher removal rate than smaller particles. The street sweeper efficiency data is presented by frequency, rather than equipment type. The street sweeper efficiencies are averages for specific pollutants and are representative of different technologies.

Table 24-26 provide interim pollutant removal rates for TSS, TP and TN using the conceptual model. Given the availability of data in the literature the frequencies for sweeper efficiencies for TSS include monthly, twice a month, weekly, twice weekly or more.

For a given set of assumptions and sweeping frequencies, it is expected that the range in pollutant removal rates from street sweeping for TSS, TP, and TN are: 16 – 32%, 4-8% and 4-9%, respectively.

Table 24. An estimate of the expected average pollutant removal rate for total solids using street sweeping.

Discount Factor	Percent	Amount of available solids
Total street pollutant		100
Particulate-phase		100
Washoff	15	85
Fugitive dust loss	10	75
TREATABLE LOAD 90% of street dirt within 12 inches of curb		67.5
Street Sweeper Efficiency (%) based on a range of frequencies		
Frequency	**Percent Reduction**	**Amount material removed (g)**
Monthly/Bimonthly ~10-20 times/year	30	20
Twice a month	45	30
Weekly	45	30
Twice a week	59	40
Reduced effectiveness due to parked cars	20	
Monthly	24	16
Twice a month	36	24
Weekly	36	24
Twice a Week	47	32
RANGE IN POLLUTANT REMOVAL RATE FOR TOTAL SOLIDS		16 - 32 %

Table 25. An estimate of the expected average pollutant removal rate for total phosphorus using street sweeping.

Discount Factor	Percent	Amount of total phosphorus
Total street pollutant		100
Particulate-phase	54%	54
Washoff	15% or 8.1 units	45.9
Fugitive dust loss	10% or 5.4 units	40.5
TREATABLE LOAD 90% of street dirt within 12 inches of curb		36.5
Street Sweeper Efficiency (%) based on a range of frequencies		
Frequency	**Percent Reduction**	**Amount material removed**
Monthly	*12*	4
Twice a Month	*18*	*7*
Weekly	18	7
Twice a Week	26	10
Reduced effectiveness due to parked cars	20	
Monthly	10	4
Twice a Month	*15*	*5*
Weekly	15	5
Twice a Week	21	8
RANGE IN POLLUTANT REMOVAL RATE FOR TOTAL PHOSPHORUS		4-8 %

Table 26. An estimate of the expected average pollutant removal rate for total nitrogen using street sweeping.

Discount Factor	Percent	Amount of total nitrogen
Total street pollutant		100
Particulate-phase as TKN	33%	33
Washoff	15% or 5 units	28
Fugitive dust loss	10% or 3.3 units	24.7
TREATABLE LOAD 90% of street dirt within 12 inches of curb		22.2
Street Sweeper Efficiency (%) based on a range of frequencies		
Frequency	Percent Reduction	Amount material removed
Monthly	23	5
Twice a Month	*35*	*8*
Weekly	35	8
Twice a Week	50	11
Reduced effectiveness due to parked cars	20	▨
Monthly	18	4
Twice a Month	*28*	*6*
Weekly	28	6
Twice a Week	40	9
RANGE IN POLLUTANT REMOVAL RATE FOR TOTAL NITROGEN		4 – 9 %

7.2 Catch Basin and Storm Drain Inlet Cleanout Interim Pollutant Removal Efficiencies

The model developed by Lager et al. (1979) has been used to provide data to support the interim pollutant removal rates for TSS, TN and TP and represents catch basin cleanout under best conditions. Best conditions refers to catch basins that are clean, material accumulation is less than 50% of the storage capacity and flow rates through the catch basin are low (i.e., 0.25 cfs). Although, Mineart and Singh (1994) and Pitt and Bissonnett (1984) provide more recent data, the boundary conditions and discount factors defined by the conceptual model follow more closely with Lager et al. (1979). However, it will be shown that the interim pollutant removal efficiencies are similar in range to those suggested by other researchers.

The factors reported that affect pollutant removal efficiency by catch basins are particle size, cleanliness of the catch basin and cleanout frequency. Since catch basins are designed to retain coarse-grained particles, fine-grained particles (e.g. < 250µm) often pass through without trapping. Table 10 provides an estimate of the fraction of wet sediments for TSS, TP and TN (Lager et al. 1977). Monitoring data generated through this project will provide a better estimate of the fraction of particle size classes within sediments captured in storm drain inlets and catch basins. It is assumed that particles larger than 246μm are retained in the basin while only a fraction of the particles smaller than 246 μm are retained. An average of the field and model studies presented by Lager et al. (1979) for particles < 250μm is used to provide an estimate for the fraction retained (see Table 21). For example, in Table 27 of the 100 units of total sediment, it is assumed that about 80% of the material is less than 246μm. It is estimated that 55% of this fraction is retained. Therefore of the 100 units of sediment, 74.5 units remain in the catch basin, where,

$$43 + (0.55*57) = 74.$$

Using annual and biannual cleanout frequencies, a further discount factor is applied to the material retained in the catch basin for later removal. If the catch basin has an accumulation of material less than 50% of its storage capacity, then this value may be considered the pollutant removal rate for a clean catch basin under best conditions. A further discount is applied if the storage capacity of the catch basin is at 50% and is considered a dirty catch basin.

Tables 27-29 present interim removal rates for TS, TP and TN using a set of assumptions that will be further refined following that analysis of survey and monitoring data as part of this project. Total solids have the greatest removal rate and exceed the reported limits provided by Pitt and Bissonnett (1984) who estimated a maximum removal rate of 25% given a semi-annual cleanout frequency. However, the pollutant removal rate of 28% for semi-annual cleanout more closely approximates Pitt and Bissonnett (1984) when the catch basin has reduced capacity. There is negligible removal rate for total phosphorus, not exceeding 2%. The pollutant removal rate for total nitrogen (expressed only as TKN) of 2.6-10% is within the expected range provided by Pitt and Bissonnett (1984) of 5-10% for semiannual cleaning.

Table 27. Pollutant removal rate for total solids from annual catch basin cleanouts.

Factor	**Trapping Efficiency (%)**	**Amount of sediment**
Particulate fraction	100%	100
Sediment fraction < 246 µm	57%[a]	
Sediment fraction > 246 µm	43 %	
Percent of particles <250µm retained	55%	74
Cleanout frequency		
Annual	39%	29
Semi-annual	75%	56
Reduced efficiency due to Reduced capacity:	50%	
Annual		14
Semi-annual		28
POLLUTANT REMOVAL RATE FOR TOTAL SOLIDS		Max: 56% Min: 15%

[a] This sediment trapping efficiency may be considered high, as stormwater runoff data show that about 80% of the particles are less than 35µm.

Table 28. Pollutant removal rate for total phosphorus from annual catch basin cleanouts.

Factor	**Trapping Efficiency (%)**	**Amount of total phosphorus**
Total amount of sediment		100
Particulate Fraction	54%	54
Sediment fraction < 246 µm	46%	27
Sediment fraction > 246 µm	4 %	
Percent of particles <250µm retained	60%	27
Cleanout frequency		
Annual	3%	1
Semi-annual	6%	2
Reduced efficiency due to dirty catch basin:	50%	
Annual		<1
Semi-annual		<1
POLLUTANT REMOVAL RATE FOR TOTAL PHOSPHORUS		Max: 2 Min: < 1%

Table 29. Pollutant removal rate for total nitrogen from annual catch basin cleanouts.

Factor	Trapping Efficiency (%)	Amount of total nitrogen
Total amount of sediment		100
Particulate Fraction		
Sediment fraction TKN < 246 µm Sediment fraction TKN > 246 µm	29 21	100
Percent of particles <250µm retained	60%	37
Cleanout frequency		
Annual	14%	5
Semi-annual	27%	10
Reduced efficiency due to dirty catch basin:	50%	
Annual		3
Semi-annual		5
POLLUTANT REMOVAL RATE FOR TOTAL NITROGEN		Max: 10% Min: 3%

8. Application of Project Monitoring Effort

The conceptual model provides a best estimate for interim pollutant removal rates that may be expected from street sweeping and storm drain and catch basin cleanout practices. Although the rates are reasonable, they reflect the compilation of research studies across the United States under many different conditions and may not necessarily reflect conditions specific to the Chesapeake Bay watershed. Further, the conceptual model is a simplified representation of reality that will be improved upon as data from the monitoring efforts of the project are complete. The field monitoring component of this project will provide data to verify and, or adjust these pollutant removal rates.

The study areas are Catchments F and O within Watershed 263 in Baltimore, MD are ultra-urban catchments. The data generated from the monitoring program will be based on:

- baseflow and storm event sampling,
- two different street sweeping treatments, and
- street dirt and storm drain sediment pollutant characterization.

The effect of street sweeping and storm drain/catch basin cleanouts are being monitored separately as well as combined practices. The City of Baltimore DPW, in coordination with the Baltimore Ecosystem System has been intensively monitoring Catchments F and O baseflow and storm event sampling since May 2004 and provides a baseline record for comparative purposes. Extensive monitoring within Baltimore County will provide accumulation rates and chemical characterization of sediment within catch basins, by land use and physiographic province. Analyses of the municipal practices survey of Phase 1 and Phase II communities within the Chesapeake Bay will further aid in quantifying these rates.

Statistical analyses of pollutant loads before and during the street sweeping treatments will be estimated to determine if street sweeping and the combined effects of street sweeping and storm drain cleanouts will improve stormwater quality. Metrics of the amount of material removed from the streets and storm drains will also be estimated. For example, pollutant removal efficiency is defined as:

$$\frac{\text{(Street dirt load before sweeping -- street dirt load after sweeping)}}{\text{street dirt load before sweeping}} \times 100,$$

and will be compared with the values shown in Table 24-26. Additional analyses to determine the impact of street sweeping on stormwater runoff include relating the pollutant removal rates to percent of impervious area swept, pounds of material removed per impervious area or curb mile swept. Source area sampling of the streets will provide an estimate of accumulation rates, total street dirt load and its physical and chemical characteristics.

Pollutant removal rates based on land use with land cover characteristics of the drainage basin (e.g. percent impervious cover) will be estimated given the data being collected in Baltimore County, as part of this study. Material and pollutant accumulation rates and sediment quality is being characterized and quantified. A more limited, but similar data will be generated for select catch basins in Catchments F and O to evaluate the combined practices of street sweeping and catch basin cleanout.

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Appendix A

National and Chesapeake Bay Stormwater Event Mean Concentrations

A comparison of National and Chesapeake Bay Stormwater Event Mean Concentrations

The event mean concentration statistics presented in Table A.1 is taken from NPDES stormwater observations collected from Phase I communities located in the Chesapeake Bay watershed as included in the National Stormwater Quality Database (NSQD version 1.1 and available at: rpitt.eng.ua.edu/Research/ms4/mainms4.shtml). Data for TSS, nitrogen and phosphorus are presented. It should be noted that the value for TN is not equal to the sum of dissolved and TKN likely due to the small sample size for TN compared to the other nitrogen parameters. The database for the Chesapeake Bay Watershed represent residential, mixed residential, commercial, mixed commercial, industrial and mixed open space land uses. The land uses not included in the database for the Chesapeake Bay watershed includes: open space, freeways, institutional, mixed industrials and mixed freeways as they were not a dominate land use type.

For the Chesapeake Bay, more than 1330 events were collected in 19 counties and 1 state highway department in Maryland and Virginia. This is approximately one-third of the full database that contains 3,700 events from 62 communities and 3 highway administrations in 17 States. A list of the communities included in the database and represented in the statistics below is provided in Table A.2. A total of 71 single land use sites are included in the database while the remaining sites have mixed land uses. Only sites with more than 7 observations were included in the analysis. From the 49 Virginia sites, 32 have more than 7 observations, while only six of the 22 Maryland sites satisfy this restriction. Although only few sites were found in Maryland all of them were well represented. Maryland has the site with more observations in the database (Kent Land Village, 60 observations); in addition, none of their sites have less than 18 storm events.

The median concentrations for the Chesapeake Bay communities are similar to the national values, with the exception of TSS , nitrite-nitrate-N, and TP that are all slightly lower. The median value of the event mean concentration is presented, rather than the average, given the large variation for most parameters as indicated by the coefficient of variation (CoV) values greater than one. However, the stormwater concentrations for the Chesapeake Bay communities are slightly less variable compared to national values.

Table A.1. A comparison of stormwater concentrations for TSS, N and P between National and Chesapeake Bay Watershed communities. The value in parantheses is the sample size.

	National	Chesapeake Bay	National	Chesapeake Bay
Parameter (mg/l)	Median		CoV	
TSS	59.13 (3493)	43.00 (1214)	1.78	1.47
N02+NO3	0.60 (3075)	0.56 (1216)	0.97	0.85
Nitrogen Total	1.90 (570)	2.10 (21)	1.69	0.59
Nitrogen Kjeldahl Total	1.40 (3191)	1.40 (1221)	1.25	1.12
Phosphorous Dissolved	0.13 (2477)	0.13 (742)	1.57	1.59
Phosphorous Total	0.27 (3285)	0.24 (1208)	1.51	1.11

	National	Chesapeake Bay	National	Chesapeake Bay
	Min		Max	
TSS	3.00	3.00	4800.00	1196.00
N02+NO3	0.01	0.01	18.00	7.30
Nitrogen Total	0.20	0.64	90.10	6.42
Nitrogen Kjeldahl Total	0.05	0.05	66.40	36.00
Phosphorous Dissolved	0.00	0.01	6.97	5.45
Phosphorous Total	0.01	0.02	15.40	6.72

from the NSQD database at http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

Table A.2. Urban Monitoring Locations in the Chesapeake Bay Watershed represented in the National Stormwater Quality Database (NSQD, version 1.1) (from Pitt and Maestre 2004).

MARYLAND

Land use	LOCATION_ID	Number of Samples	Jurisdiction	Site Name	Impervious Cover %	Qualifier Impervious Cover	Drainage Area (Acres)
ID	MDAACOMW	2	Anne_Arundel_County	Midway industrial park MW	94		5
RE	MDAACOOD	3	Anne_Arundel_County	Odenton OD	41		28
CO	MDAACOPP	26	Anne_Arundel_County	Parole Plaza PP	85		25
RE	MDAACORK	3	Anne_Arundel_County	Rolling Knolls RK	41		12
RE	MDBACOSC	23	Baltimore_County	Spring Branch SC	30		83.5
ID	MDBCTYFM	2	Baltimore_City	FM			45.96
RE	MDBCTYHO	3	Baltimore_City	Home land HO			354.09
RE	MDBCTYHR	1	Baltimore_City	Herring Run HR	54		38.8
RE	MDCLCOCE	3	Carroll_County	Candice estates CE			22.35
CO	MDCLCOJS	3	Carroll_County	John street JS			20
RE	MDHACOBP	18	Harford_County	Brentwood_Park_Woodland_Hills	16	E_Rv	69.7
RE	MDHOCOGM	1	Howard_County	Green Moon GM	38		29.5
CO	MDMOCOBC	2	Montgomery_County	Burtons ville crossing BC	83	E_Rv	14.2
ID	MDMOCOCV	29	Montgomery_County	Coles villeCV	55	E_Rv	11.5
RE	MDMOCONV	3	Montgomery_County	Venture V	57	E_Rv	75.4
RE	MDMOCOQA	3	Montgomery_County	Quaint Acres QA	45	E_Rv	34.2
ID	MDMOCOSL	3	Montgomery_County	South town lane SL	92	E_Rv	81
CO	MDMOCOWP	3	Montgomery_County	Wheaten plaza WP	96	E_Rv	70
CO	MDPGCOS1	22	Prince_Georges_County	Aterm plaza S1	47	E_Rv	19.7
RE	MDPGCOS2	60	Prince_Georges_County	Kent land village S2	45	E_Rv	57.3
RE	MDPGCOS4	3	Prince_Georges_County	wayne place S4	33	E_Rv	102.5
ID	MDPGCOS5	3	Prince_Georges_County	John Hanson S5	83	E_Rv	41.3

VIRGINIA

Land use	LOCATION_ID	Number of Samples	Jurisdiction	Site Name	Impervious Cover %	Qualifier Impervious Cover	Drainage Area (Acres)
RE	VAARLCV2	9	Arlington	Colonial_Village_CV2	35		24.7
RE	VAARLLP1	8	Arlington	Little_Pimmet_LP1	35		38.7
CO	VAARLRS3	8	Arlington	Randolph_Street_RS3	74		14
ID	VAARLTC4	13	Arlington	Trades_Center_TC4	39		36
CO	VACHCCC4	13	Chesterfield_County	CoverLeaf_Mall_CC4	80		60
RE	VACHCCC5	12	Chesterfield_County	Buck_Rub_Drive_CC5	50		10
RE	VACHCN1A	4	Chesterfield_County	Gates_bluff_1A	10		10
RE	VACHCN2A	3	Chesterfield_County	Helmsley_road_2A	20		60
RE	VACHCOF3	10	Chesterfield_County	Kings_mill_road_OF3	20		13.5
RE	VACHCOF5	15	Chesterfield_County	Laurel_oak_road_OF5	50		55.6
RE	VACPTC1A	8	Chesapeake	Briarfield_Drive_C1A	25		130
RE	VACPTYC1	7	Chesapeake	Etheridge_rd_Mt_Pleasant_Rd_C1	25		57
RE	VACPTYC3	15	Chesapeake	Horse_Run_Ditch_C3	50		32
CO	VACPTYC4	14	Chesapeake	Woodford_Square_Along_Battlefield_Blvd_C4	85		28
ID	VACPTYC5	15	Chesapeake	Cavalier_Industrial_Park_C5	57		16
RE	VAFFCOF1	3	Fairfax_County	Apple Ridge Road			32.3
RE	VAFFCOF3	2	Fairfax_County	Onley Road			63.9
CO	VAFFCOF4	12	Fairfax_County	Green Look Place	70	E_A	108.8
RE	VAFFCOF5	3	Fairfax_County	Oakton Terrace Road			39.7
CO	VAFFCOF6	14	Fairfax_County	Fairview Park Drive	21	E_A	213.4
RE	VAFFCOF7	13	Fairfax_County	Lakeview Drive	25	E_A	49.9
RE	VAFFCOF8	2	Fairfax_County	Pumphrey Drive			57.5
RE	VAFFCOF9	12	Fairfax_County	Rock Ridge Road	50	E_A	63.8
ID	VAFFOF10	3	Fairfax_County	Boston Boulevard			82
ID	VAFFOF11	11	Fairfax_County	Prosperity Avenue	66	E_A	37.9
CO	VAHATYH1	18	Hampton	Commerce_Drive_H1	80		115
ID	VAHATYH2	19	Hampton	Mingee_Drive_H2	70		47
RE	VAHATYH3	17	Hampton	Hampton_Club_H3	40		18
RE	VAHATYH4	16	Hampton	Bay_Avenue_H4	25		134
RE	VAHATYH5	17	Hampton	Willow_Oaks_Boulevard_H5	25		35
CO	VAHCCOC1	2	Henrico_County	Dickens_Place_C1			65
CO	VAHCCOC2	1	Henrico_County	Carousel_Lane_C2			70
ID	VAHCCON1	2	Henrico_County	Tomlyn_Street_N1			75
ID	VAHCCON2	3	Henrico_County	Impala_Drive_and_Galaxy_Road_N2			23
RE	VAHCCOR1	2	Henrico_County	Prestwick_Circle_R1			40
RE	VAHCCOR2	3	Henrico_County	Westbury_Drive_R2			70
RE	VANFTYN2	22	Norfolk	Modoc Avenue N2	25		97
RE	VANFTYN3	19	Norfolk	Liitle creek road N3	37		27
CO	VANFTYN4	19	Norfolk	Military circle N4	70		43
RE	VANFTYN5	20	Norfolk	Sewel's point N5	25		39
RE	VANNTNN1	2	Newport_News	Glendale_Road_NN1	40		75
CO	VANNTNN3	8	Newport_News	Patrick_Henry_Mall_NN3	85		24
CO	VAPMTYP1	14	Portsmouth	Cradoc Shopping center P1	68		27.2
RE	VAPMTYP2	15	Portsmouth	West park homes P2	36		101.1
RE	VAPMTYP4	15	Portsmouth	Edgefield apartmentsP4	39		35.3
RE	VAPMTYP5	16	Portsmouth	South hampton P5	12	E_A	53.5
RE	VAVBTYV1	20	Virginia_Beach	Bow creek V1	29		63
RE	VAVBTYV2	20	Virginia_Beach	Salem Road V2	29		260
ID	VAVBTYV4	17	Virginia_Beach	Viking Drive V4	55		29