Implementing a Sustainable Storm Water Management Program in an Urban Center - Baltimore, Maryland

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Abstract
In the Chesapeake Bay, eutrophication resulting from excess nutrient loading is the main cause of poor water quality and aquatic habitat loss. Major sources of nutrients to the Chesapeake Bay include agricultural runoff, wastewater treatment plants and stormwater, specifically urban stormwater which is the focus of this research. Although reducing nutrient loads is a priority, stormwater management practices in an urban center also have the potential to improve public health and quality of life in local communities. To achieve these goals, municipalities must adopt a holistic approach to stormwater management, which includes extensive public education and outreach. Municipalities also need the knowledge to select sustainable management practices with consideration for environmental, social and economic concerns. Two specific practices which have the potential to positively impact both urban stormwater quality and public health and attitude are street sweeping and storm drain cleanouts. These practices are already implemented over a large footprint of Baltimore, Maryland and this research aims to determine how to maximize their effectiveness. Performance of these two practices is being examined through a collaborative research effort involving a literature review, a multi-state municipal survey, and an intensive field monitoring program in southwest Baltimore City. The field monitoring component focuses on nutrient and sediment loads in stormwater, and will result in improved estimates of the potential pollutant reductions possible through street sweeping and storm drain cleanout. In addition to examining water quality changes, public health effects of these practices will be investigated through a risk assessment for contaminants found in particulate matter collected from street surfaces. Results of this research will enable municipalities within the Chesapeake Bay watershed to make stormwater management decisions which reduce nutrient inputs and simultaneously improve quality of life in urban communities.

Introduction
In the United States, more than 60 percent of coastal rivers and bays are categorized as moderately to severely degraded by nutrient pollution, and this problem is particularly acute in the mid-Atlantic states (Clement et al. 2001). In the Chesapeake Bay, eutrophication resulting from excess nutrient loading is the main cause of poor water quality and aquatic habitat loss, and reducing nutrient inputs to the Bay is a critical element of restoration efforts. The three major contributors of nutrient pollution to the Chesapeake Bay include effluent from wastewater treatment plants, agricultural runoff, and urban stormwater (Chesapeake Bay Program 2006). Major sources of nutrients to the Chesapeake Bay are included in Table 1, along with potential management options to reduce these contributions.

Table 1: Common sources of nutrients to the Chesapeake Bay and potential management options to reduce their contributions.

Nutrient Source	Type	Management Options
Wastewater Treatment Plant Effluent	Point	- Limit concentration in effluent - Recycle water - Public education to reduce water consumption
Agricultural Runoff	Nonpoint	- Riparian buffers - Limit manure/fertilizer application - Regulate animal waste disposal practices
Urban Stormwater Runoff	Nonpoint	- Reduce impervious cover - Practice low impact development - Source control - Best Management Practices (BMPs)
Atmospheric Deposition	Nonpoint	- Restrict discharges from fossil fuel burning facilities
Groundwater Discharge	Nonpoint	- Septic tank restrictions

To date, the majority of action has been focused on reducing inputs from wastewater treatment plants by upgrading plants with technology to reduce nitrogen and phosphorus concentrations in their effluent. However, it is estimated that point sources contribute only about 20% of nitrogen delivered to Chesapeake Bay, while nonpoint sources contribute the remaining 80% (U.S. Environmental Protection Agency 2002a). Clearly, to improve the health of the Bay, nonpoint sources like agricultural and urban runoff must be aggressively addressed. Although agricultural runoff is considered the single greatest source of nutrients to the Bay, contributing about 40% of nitrogen and 50% of phosphorous loads, it is particularly challenging to regulate (Chesapeake Bay Foundation 2003). Therefore, many municipalities in the Chesapeake Bay watershed are primarily focused on urban stormwater management.

The Chesapeake Bay Program (2006) estimates that urban runoff is responsible for 16% of the phosphorus, 11% of the nitrogen, and 9% of the sediment loads entering the Chesapeake Bay. In addition to delivering pollutants to the Bay, urban stormwater also causes flooding, stream bank erosion and habitat degradation. To reduce the negative effects urban landscapes have on water quality, the Chesapeake Bay Program (2006) recommends reducing impervious cover and its impact through low impact development practices, source reduction, and best management practices (BMPs). BMPs are essentially any structural or non-structural practice that reduces the quantity and improves the quality of stormwater in a cost-effective manner. Examples of traditional BMPs include detention basins, grass swales and vegetated buffers. However, in an urban environment, implementation of stormwater BMPs is often limited by space and budget constraints, and staffing shortages. Nevertheless, there are alternative stormwater management options available which urban municipalities can implement to both improve water quality and positively impact public health and attitude. To achieve these multiple objectives, municipalities must adopt a holistic approach and develop a sustainable stormwater management program. In this work, a holistic approach to stormwater management is explored, and Baltimore, Maryland is provided as an example of an urban center working to develop a sustainable stormwater program and restore communities. Specifically, a collaborative project in southwest Baltimore City is described, which emphasizes community participation and street sweeping and storm drain cleanouts as potential stormwater BMPs.

A Holistic Approach to Sustainable Stormwater Management

A holistic approach to stormwater management implies focusing not only on the immediate problem of polluted stormwater runoff but on all the potential sources and their underlying causes in a specific watershed. For instance, municipalities should work beyond simply implementing a few individual BMPs to fulfill permit requirements, and instead select practices with an understanding of their interactions and how they will perform in synergy to impact the watershed. In addition to realizing the interactions among practices, municipal operators should acknowledge the interconnectedness of their local environment and the local community. For example, an urban stormwater management program should address the fact that nearly all street litter is intentionally left there by humans. Therefore, a cornerstone of any effective urban stormwater management program should be public outreach and education, along with public provisions that encourage alternate behavior (i.e. using trash receptacles). Overall, gaining community support and adopting a holistic approach to stormwater management will make it possible for municipalities to design and implement a sustainable, long term program. A sustainable stormwater management program incorporates environmental, social and economic concerns in the decision making process. Additionally, a sustainable stormwater management program should control and reduce the impact of current runoff and plan for future challenges with respect to population growth and landscape changes.

Baltimore, Maryland – Watershed 263

In Baltimore, a unique and collaborative project is currently underway to develop a sustainable stormwater management program which aims to ultimately restore an impoverished watershed. The project site is a 930 acre area called watershed 263 (outfall number) located in southwest Baltimore City. Several unique characteristics of the research site make it a challenging and exciting study location. First, impervious cover in watershed 263 averages close to 75%, which is significantly higher than the 40% city-wide average in Baltimore. Also, watershed 263 is absent of any flowing surface waters - all area streams were piped and buried about 100 years ago, creating 43 miles of pipes which serve as the main components of the storm drain system (Center for Watershed Protection 2006a). Within the storm drain system, there is a substantial dry-weather baseflow, which is likely due to sewage and groundwater entering the system through leaky pipes (Richardson 2006). Nearly all of the neighborhoods within watershed 263 have suffered moderate to severe economic decline due to suburbanization and the loss of industrial development. Economic decline in watershed 263 has led to a large concentration of vacant houses and lots, a high unemployment rate and a significant portion of the population living below the poverty level (Center for Watershed protection 2006a).

Watershed 263 has received significant research attention in the past several years from a number of partners including the federal government (U.S. Forest Service), the state (University of Maryland, Baltimore County), Baltimore City (Department of Public Works), and non-profits (Center for Watershed Protection, Parks & People Foundation). However, what sets this urban environmental research project apart from many others is a commitment to community involvement and participation. The key to community involvement is a partnership between the Baltimore City Department of Public Works and the Parks & People foundation, an organization dedicated to improving quality of life for Baltimore residents. The Parks & People foundation worked to raise public awareness in the watershed by holding over 40 community meetings to explain the restoration plan, along with separate community forums to hear resident feedback. Since the initial meetings, an advisory group of about 20 concerned residents has been formed to represent each geographic neighborhood in planning decisions (Richardson 2006).

There are a number of innovative stormwater management projects being implemented in watershed 263, and two of the most notable are the schoolyard greening initiative and the Clean & Green program. The schoolyard greening project has removed more than 1.5 hectares of unused asphalt from several public schools and replaced it with green lawns and gardens. This program uses critical area and stormwater management credits to reduce impervious area in the watershed and improve aesthetics, while also offering environmental education opportunities for elementary and middle school students. These schools involve the students in the redesign of their schoolyards and incorporate the planting of trees and gardens into the school curriculum. The Clean & Green program is a partnership between two community outreach organizations in Baltimore City developed to improve the hundreds of vacant lots across southwest Baltimore. To date, this program has converted over 330 vacant lots (about 3.3 hectares) to green space by planting grass and more than 500 trees (Center for Watershed Protection 2006a).

In addition to these high profile beautification projects, watershed 263 is also the site of an intensive field study designed to determine the effectiveness of stormwater management practices. Developed as a paired-catchment study, this research is examining the effects of various stormwater practices on the water quality of two urban catchments within watershed 263. These two catchments are very similar in size (15-16 hectares), impervious cover (67-77%), and land use (urban-residential). In each catchment, all of the water that enters the storm drain system eventually flows to one pipe. One water quality monitoring station is positioned at this combined flow pipe for each catchment, with automated water samplers deployed inside the storm drains. Water quality monitoring of both baseflow and storm events began in these two catchments in late 2004 to establish baseline data, before any new stormwater treatments were implemented in early 2006. This setup allows researchers to compare the water quality data between the two catchments during the baseline period and after different stormwater practices are implemented. The practices which are currently being studied in the paired catchments of watershed 263 are street sweeping and storm drain cleanout.

Street Sweeping and Storm Drain Cleanout

In an ultra-urban watershed there are often limited opportunities to implement traditional BMPs due to space and financial constraints, and alternative methods to control and reduce the impact of stormwater runoff are needed. Street sweeping and storm drain cleanouts are good options because they are relatively inexpensive and easy to implement in an urban watershed. Although these practices rank among the oldest techniques used to control stormwater pollution, very limited and sometimes conflicting data has been published in regard to their performance in removing nutrients and other pollutants (Burton and Pitt 2002, Sutherland and Jelen 1997, Mineart and Singh 1994, Pitt 1979). Many of the past studies on sweeping studies and storm drain/catch basin cleanout have focused on quantifying the amount of material removed, but there is a limited understanding of how these practices can be used by municipalities to effectively reduce pollutant loadings and improve or maintain water quality.

In an urban catchment, streets are recognized as a major source of pollutants to urban stormwater. Several studies have compared the pollutant contribution of streets to urban stormwater with contributions of other source areas such as: lawns, driveways, rooftops and parking lots. Streets are considered the major source of suspended solids in urban stormwater, contributing about 70 to 80%, and the second most important source of nutrients (after lawns), contributing about 20 to 30% of the nitrogen and phosphorus (Pitt 1985, Bannerman et al. 1993, Waschbusch et al. 1999). Therefore, effective street sweeping has the potential to remove this contaminated material from the street surface before a rain event transports it through the storm drain system and into receiving waters. However, past field studies, such as those performed as part of the Nationwide Urban Runoff Project (NURP) in the late 1970s and early 1980s, typically found that street sweeping was ineffective as a stormwater BMP. NURP-era street sweepers were effective at removing litter and larger particles, but were unable to pick up the highly contaminated fine particles and as a result produced no significant reduction in pollutant concentrations in stormwater runoff (Pitt 1979). In the 25 years since the NURP studies, there have been significant advances in street sweeping technology focused on increasing their ability to pick up fine particles, but whether these improvements translate to a reduction in stormwater pollutant load is still undetermined.

Specific pollutant reductions possible through municipal street sweeping are difficult to estimate based on the small number of studies completed and their differences in scope, extent, and design. However, using information from past research, the Center for Watershed Protection (2006b) developed a conceptual model to define interim pollutant removal rates for street sweeping. Using the conceptual model, estimated interim pollutant removal rates for sweeping twice a week are 32% for total suspended solids, 8% for total phosphorus, and 9% for total nitrogen.

Street sweeping programs that remove litter and particulate matter from the street surfaces not only improve the aesthetics of a city, but can also benefit public health. Particulate matter found on the street is typically contaminated with considerable amounts of metals (lead, zinc, copper) and organics (polycyclic aromatic hydrocarbons (PAHs), and pesticides). These contaminants can cause a significant health risk for children that may play in or around city streets and incidentally ingest dirt from the street surface. In addition to the risk of ingesting contaminants, fine particulate matter itself is a concern and is regulated by the U.S. Environmental Protection Agency (EPA) as particle pollution. The U.S. EPA is particularly concerned with inhalable particles 10 μm in diameter or smaller (PM_{10}) because they can enter the body where they can affect the heart and lungs and cause serious health effects (U.S. EPA 2006). Many cities with particle pollution problems are turning to street sweepers as a way to improve air quality by using specific types of sweepers that are PM_{10} certified to remove fine particulate matter. Improving air quality is one more potential benefit of a successfully implemented street sweeping program. Although, no matter how successful a street sweeping program is, some material from the street surface and surrounding areas will ultimately be transported in stormwater and enter a storm drain.

While serving as an interface between streets and sewers, storm drains also provide the important purpose of capturing and trapping solids in the stormwater. These solids and associated pollutants are temporarily stored in the storm drain until they are removed by either a large storm event or cleaning of the drains by the municipality. Although storm drain cleanouts are essential for proper function of the storm drain network, little is known about their effect on stormwater quality, particularly regarding the extent of pollutant load reduction. Only a handful of studies (Lager et al. 1977, Pitt 1985, Mineart and Singh 1994) have examined the impacts of storm drain cleanouts on stormwater quality, and the optimal frequencies for these cleanouts. Pitt (1985) found that cleaning inlets twice a year is expected to reduce concentrations of lead and total solids in urban runoff by 10 to 25%, and estimated that chemical oxygen demand (COD), nutrients, and zinc may be reduced by 5 to 10%. Pitt (1985) concluded that combining intensive street cleaning and cleaning storm drains twice a year could reduce most pollutants in urban runoff by 10%, with reduction of some heavy metals as high as 25%.

Although pollutant reductions of 10% may seem small and perhaps insignificant, it is important to remember that these practices will continue to be performed for their aesthetic and public safety benefits by Baltimore City and by most urban centers within the Chesapeake Bay watershed, regardless of their impact on stormwater. The Center for Watershed Protection (2006c) performed a survey of 16 large (greater than 100,000 people) municipalities within the Chesapeake Bay watershed and found that all but one have a street sweeping program, and all have a storm drain cleanout program. However, nearly half of the communities surveyed report street sweeping frequencies of just 2 to 4 times a year, and based on previous studies only a handful of the municipalities surveyed are sweeping frequently enough (bi-weekly or more) to realize a potential water quality benefit. A greater understanding of the relationship between water quality and sweeping frequency will be provided by the results of the ongoing field work in watershed 263.

Ongoing Work

The paired-catchment study currently taking place in watershed 263 is monitoring changes in stormwater quality with respect to changes in street sweeping and storm drain cleanouts practices. Both catchments were swept throughout the baseline period of late 2004 and 2005, and then in early 2006 street sweeping practices were increased (48% more street miles-swept twice a week) in catchment O and concurrently decreased (85% less street miles-swept once a week) in catchment F. Finally, in early 2007, storm drain cleanout operations will begin in catchment O, while catchment F remains as a control. Impacts of the new street sweeping treatments on water quality are not yet known, but some interesting results were obtained during the baseline monitoring period.

During the baseline monitoring period, the Baltimore City Department of Public Works and the U.S. Forest Service (as part of the ongoing Baltimore Ecosystem Study) monitored both the baseflow and stormwater quality in the two catchments (O and F) within watershed 263. Between 21 and 24 composite water samples were collected in each of the catchments and parameters measured include: total phosphorus (TP), total Kjeldahl nitrogen (TKN), total nitrogen (TN = TKN + nitrate + nitrite), copper (total and dissolved), lead (total and dissolved), total suspended solids (TSS), zinc (total and dissolved), fecal coliforms, *Escherichia coli* (*E. coli*), biological oxygen demand (BOD) (5-day) and fluoride. Table 2 compares the median baseflow and stormwater concentrations in catchments O and F to median Event Mean Concentration (EMC) values from the National Stormwater Quality Database (Pitt et al. 2004) for several parameters.

Table 2: Comparison of median values of select water quality parameters for baseflow and stormwater runoff at Lanvale Street (catchment F) and Baltimore Street (catchment O) monitoring stations with EMC values from the National Stormwater Quality Database.

Parameter	Units	Lanvale Station Baseflow[1]	Baltimore Station Baseflow[1]	Lanvale Storm EMC[1]	Baltimore Storm EMC[1]	National Storm EMC[2]
TP	mg/L	0.11	0.46	0.3	0.37	0.27
TN (TKN + NO_2 + NO_3)	mg/L	3.6	6.3	2.4	3.5	2
TSS	mg/L	25	3.2	52	52	58
Fecal Coliform Count	MPN/ 100 ml	4000	900	30000	90000	5081
Total Pb (dissolved + particulate)	(µg/L)	7.9	2.8	46	44	16
Pb dissolved	(µg/L)	1	2	2.5	3.5	N/A

Sources: [1]Baltimore City Department of Public Works – Water Quality Management Section (2006), [2]Pitt et al. (2004).

Median total phosphorus (TP) concentrations in the stormwater of the study catchments are 10 to 33% higher than the national median, while total nitrogen (TN) values are 20 to 75% above the national median EMC. However, even more interesting are the high baseflow concentrations of nitrogen and phosphorus. At the Baltimore Street monitoring station in catchment O, baseflow concentrations of both TP and TN are 1.5 times higher than during storm events, and the baseflow concentrations alone are about 2 to 3 times more than the national storm event median value. One possible reason for these elevated nutrient concentrations in the baseflow of watershed 263 is fugitive inputs of sewage entering the storm drain system through leaky pipes or other un-regulated sources.

Another water quality parameter that provides evidence of sewage entering the storm drain network is fecal coliform. Fecal coliform count, recorded as most probable number per 100 ml (MPN/100 ml) is used as an indicator of recent fecal contamination (American Water Works Association 1999). Median fecal coliform concentration in the stormwater of watershed 263 (20,000 - 90,000 MPN/100 ml) is an order of magnitude greater than the national stormwater median (5,081 MPN/100 ml). In the U.S, individual states can develop their own fecal coliform standards for wastewater treatment plant discharges, so standards vary from about 2 to 5,000 MPN/100 ml, but according to Metcalf and Eddy (2003) the most common standard for receiving waters is 200 MPN fecal coliform/100 ml. Therefore, the amount of sewage and its associated contaminants entering the Chesapeake Bay through Baltimore's stormwater runoff is unacceptably high. Baltimore-area waters have long been contaminated by untreated discharges of raw sewage from Baltimore City's aging wastewater collection system. In 2002 the City of Baltimore reached a joint settlement with the Department of Justice, the EPA, and the State of Maryland to address this problem. Under the settlement, Baltimore agreed to undertake a system-wide, long-term program, which includes increasing the capacity of its collection system and eliminating physical overflow structures by June 2007 and completing an extensive sewer upgrade by 2016 (U.S. EPA 2002b).

The median concentrations of lead found in watershed 263 stormwater are nearly three times the national median and these data also demonstrate the important contribution of particulate matter to the pollutant load in stormwater. In both catchments, more than 90 percent of the total lead is associated with the particulate matter or suspended solids in the stormwater. Lead and other metals often strongly associate with solids in stormwater and to help understand this relationship, field work in watershed 263 also includes monitoring the quantity and quality of particulate matter found on the street surface.

Street particulate matter sampling began in mid-2006 and occurs at least once a week on three select streets within catchment O. Samples are collected by vacuuming 10 to 20 - 15 cm wide strips extending from the curb to the crown of the street on each of the three streets, which are combined together to form a composite sample. These samples are collected at various times including before and after street sweeping, and following a rain event and then sent to Baltimore County lab for particle size and chemical analysis. The chemical analysis is performed on three size fractions (< 63 µm, 62 - 250 µm and 250 - 1000 µm) and includes the following parameters: TKN, TN, TP, orthophosphates (OP), Cu, Pb, Zn and Cd. Results of the nutrient and metal analysis are not yet available, and to date, no conclusion can be made about the impact of street sweeping on the quantity or quality of particulate matter present on the street. The effect of street sweeping frequency on stormwater quality also remains undetermined, but our hypotheses are that increasing the percentage of street miles swept will improve stormwater quality, and similarly increasing the street miles swept in addition to storm drain cleanouts will improve stormwater quality in an urban catchment.

The outcome of this intensive field study in watershed 263 will provide municipalities with potential nutrient and sediment reductions possible through specific street sweeping and storm drain cleanout frequencies. This research is also increasing awareness of the environmental and public health benefits of these two practices among municipal operators and members of local communities. This knowledge may encourage municipalities within the Chesapeake Bay watershed to extend and intensify their current programs and ultimately incorporate these practices as effective components within their stormwater management plans.

The next phase of the ongoing watershed 263 restoration project, scheduled to begin in mid-2007, will be the installation of dozens of innovative stormwater management practices. These will be customized infiltration practices, specially designed by the Center for Watershed Protection, to treat small areas, such as the region surrounding a storm drain inlet. These practices will include elements of landscaping and bioretention which will have an aesthetic appeal to the local community residents (Center for Watershed Protection 2006a). Although Baltimore City is concerned with their current National Pollutant Discharge Elimination System (NPDES) permit, which calls for the removal and restoration of 20% of the impervious surfaces in the city, improving the quality of life for inner city residents is also a priority. Public attitude of watershed 263 residents is being assessed throughout this project in a number of ways including an analysis of the frequency of trash complaints to the city's non-emergency telephone call system, multiple surveys, and an evaluation of select quality of life indicators.

Conclusions

After more than 30 years of intensive effort to restore the health of the Chesapeake Bay, in terms of both public resources and attention, the lack of progress achieved is staggering (Chesapeake Bay Foundation 2006). Significant reductions in large point sources have been accomplished with little change in the overall water quality of the Bay. It is now time to adopt alternative approaches at the local level to address nonpoint sources like stormwater runoff. However, all efforts to maintain and restore the health of the Chesapeake Bay are also challenged by the continued development and urbanization of the watershed. Census data shows that from 2000 to 2005, the population in the watershed increased by 170,000 people each year, or about 466 people each day (Blakenship 2006). Accelerated population growth will increase the amount of stormwater runoff, and effective sustainable stormwater management programs are essential for urban centers to deal with these changes. The health of the Chesapeake Bay depends on the actions of every single citizen in the watershed and the cumulative benefit of all community-based watershed programs. The collaborative effort to restore watershed 263 in Baltimore, Maryland is an excellent example of how community involvement and creative partnerships can help a municipality do its part to restore the Chesapeake Bay.

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