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Applicability of low impact development in the urban environment

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APPLICABILITY OF
LOW IMPACT DEVELOPMENT
IN THE URBAN ENVIRONMENT.

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I. INTRODUCTION

As cities have developed more intensively over time, runoff of rainfall after storms have created significant flooding problems. In some cases this runoff has also lead to health hazards with the spreading of disease. With the growth of these problems, several potential solutions have emerged. One such set of solutions is Low Impact Development (LID) methods. The focus of this paper is to determine the applicability of implementing (LID) stormwater management methods in urban areas to reduce stormwater runoff volume and pollutant loadings. Specifically, the paper focuses on the use of Low Impact Development on commercial and institutional land uses in urbanized areas.

The paper first introduces some of the background issues associated with LID, including the history stormwater management, an understanding of stormwater as it relates to the hydrologic cycle, and a discussion of associated stormwater management issues. The second part of the paper discusses the regulatory framework for stormwater management including national and local policies. The third section introduces LID and examines the particular methods appropriate for commercial or institutional land uses in urbanized areas: bioretention, permeable pavements, and rain barrels. Case studies of urban LID projects are presented in the fourth section. The fifth section discusses the obstacles to implementing LID and discusses possible ways to encourage LID, specifically through stormwater utility credits. Finally, the last section presents conclusions and recommendations.

Although LID was initially developed in a low-density residential setting, the case studies reviewed in this paper suggest the LID methods can reduce stormwater runoff volume and pollution in urban areas with medium and high-density land uses. Additionally, the LID methods can be adapted for use on large commercial and institutional land uses. This paper provides an overview of relevant cases and a better understanding of LID implementation for property owners and municipalities.

History of Stormwater Management

Stormwater management has continually evolved over the last 200 years. Debo and Reese (2003) have identified nine paradigm shifts in stormwater management. The nine paradigms represent the shifting viewpoints about how to manage stormwater.

1. Ditches to convey stormwater to another location.
2. Piping stormwater to another location
3. Separating stormwater from other wastewater in pipes
4. Detention of the stormwater in holding areas such as human-made lakes and ponds.
5. Computer modeling, which avoids flooding by engineering better designs.
6. Pollution issues and the effort to eliminate pollution in stormwater.
7. Integration of ecology into stormwater management practices.
8. Watershed management
9. Introduction of green buildings, sustainable development and low impact development all in an effort to manage stormwater in holistic environmental manner.

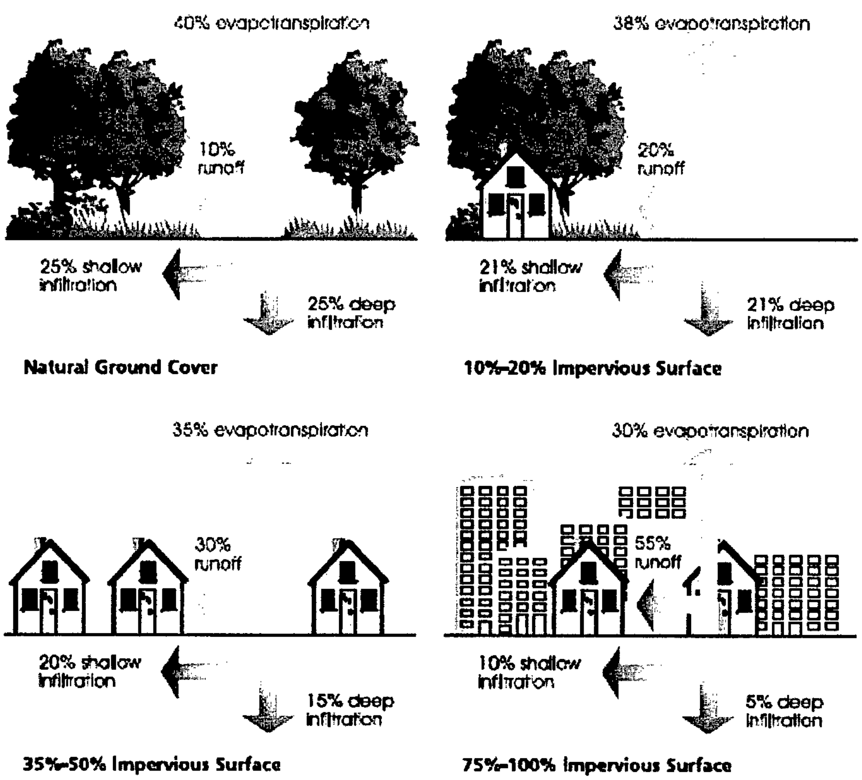
Within these nine paradigms, three basic stormwater management methods are utilized. Conveyance systems such as ditches and pipes move stormwater from one place to another. Detention ponds retain stormwater for short periods then release it slowly. Retention, filtration and infiltration systems that hold stormwater long enough to allow infiltration versus releasing it directly.

Unfortunately, stormwater runoff remains an important contributor to water pollution throughout the U. S. The Environmental Projection Agency identifies stormwater runoff and all other nonpoint source discharges as the "largest source of water quality problems" (EPA 2003d) Though paradigm shifts in stormwater management have occurred, they have not evolved uniformly across the United States. Each municipality tends to shift to a new paradigm as it encounters stormwater management problems. These shifts often accompany dramatic increases in urbanization.

Stormwater management attempts to addresses two basic issues: runoff quantity and quality. Stormwater runoff is the leftover rainfall that is not intercepted by vegetation, infiltrated through the ground, captured in depressions or evaporated. The quantity of stormwater runoff is related to the amount of runoff that enters the stormwater management system. The quality of stormwater is related to the amount of pollutants in the runoff.

When addressing the quantity of stormwater, two characteristics of runoff are important: volume and velocity. Prior to development, runoff can range from 10-30% of the total rainfall depending on the existing soil conditions and level of development of impervious area (Coffman 2000). Impervious areas refer to any type of structure that eliminates the infiltration of stormwater into the ground. This includes, but is not limited to, buildings, driveways, sidewalks, parking lots, and roads.

Figure 1 illustrates how an increase in impervious areas decreases the infiltration capability of the land. As the percent of development increases, the amount of stormwater that is infiltrated decreases drastically from as much as 50% under natural conditions to 15% under high development conditions.



Source: Coffman 1999

Figure 1: Runoff Variability with Increases in Impervious Surface

In addition to the increase in the volume of runoff, the velocity of the runoff also increases with development. As defined by Debo and Reese (2003), time of concentration is "maximum time for water to travel through a watershed." As runoff travels over impervious areas and gains velocity, the opportunity for infiltration decreases because the time of concentration decreases as velocity increases. Generally, an increase in the time of concentration results in a reduction in runoff volume. Therefore, an increase in velocity reduces the time of concentration and as a result increases the volume of runoff. As runoff velocity increases, the runoff travels to receiving waters more quickly and cannot infiltrate into the ground. The increase in velocity also leads to increases in erosion of the banks of rivers, streams and creeks.

Stormwater quality declines with the increase in impervious area that accompanies urbanization. Impervious area decreases pollution filtration through the soil column and increase the ability of stormwater to transport pollutants to receiving waters. Common pollutants found in urban stormwater runoff (EPA 2003a) include sediment from development and new construction; oil, grease, and toxic chemicals from automobiles; nutrients and pesticides from turf management and gardening; viruses and bacteria from failing septic systems; road salts; and heavy metals.

Combined Sewer System Issues

Quantity and quality of stormwater are particularly important issues for municipalities with Combined Sewer Systems (CSS), where stormwater and sanitary sewage is combined into a single conveyance system. As these communities grow, traditional development practices, runoff volume and velocity increases. The existing systems cannot handle the additional runoff. These systems were part of the "run it in pipes" paradigm (#2) combining stormwater drainage with sewage systems.

CSS systems are designed to handle the peak flows of sewage, often in the morning and evenings. Additional capacity is designed to handle low volume storm events; but, if multiple storms occur on consecutive days and the stormwater volume is too high, the system overflows. These overflows, combined sewer overflows (CSO), release untreated sewage into receiving waters.

Another aspect that is of concern for municipalities is that stormwater runoff contains pollutants that require different treatment regimes than those utilized in sanitary sewage treatment. As stated previously, gas, oil, pesticides, road salts and heavy metals are typical pollutants in urban stormwater runoff. These pollutants are not often compatible with the treatment regimes used to treat wastewater, which is designed to treat biological matter that makes up sewage waste (Debo 2003). Therefore, left untreated, the effluent from combined sewer systems may still contain these pollutants. To eliminate these pollutants additional treatment may be required.

Clearly, the primary culprit of stormwater runoff quantity and quality issues is the increase of impervious area due to development. Table 1 below describes the additional problems that an increase in impervious area creates with respect to stormwater runoff.

Table 1: Impacts from Increases in Impervious Surfaces:

Impacts from Increases in Impervious Surfaces					
	Resulting Impacts				
Increased Imperviousness Leads to:	**Flooding**	**Habitat Loss***	**Erosion**	**Channel Widening**	**Streambed Alteration**
Increased Stormwater Volume	•	•	•	•	•
Increased Peak Stormwater Flow	•	•	•	•	•
Increased Peak Stormwater Flow Duration	•	•	•	•	•
Increased Receiving Water Temperature		•			
Decreased Base Flow to groundwater		•			
Changes in Sediment Loadings to Receiving Waters	•	•	•	•	•
*e.g., inadequate substrate, loss of riparian areas, etc.					
Source: Lehner et al. 2001					

II. STORMWATER MANAGEMENT

Municipal stormwater management was initially a local function reacting to problems on an "as needed" basis. Early paradigm shifts were a response to problems encountered at the municipal level to control flooding and ensure safety of the community. Although stormwater management is still a municipal function, it is regulated at the federal, state and local level. These regulations are the result of a better understanding of how stormwater affects the environment.

Stormwater Regulation

Stormwater is primarily regulated through the Clean Water Act of 1972 (CWA) through the EPA's National Pollutant Discharge Elimination System (NPDES). NPDES is the permitting program for all facilities that discharge into United States waters (EPA 2003e). Initially the CWA and NPDES program focused on point source pollution, such as industrial pollution and municipal sewage treatment. Later when nonpoint source pollution from stormwater was determined to be a major contributor, amendments were made to CWA in 1987 to address the issue of stormwater through NPDES permits in a phased implementation cycle. Phase I beginning in 1990 addressed medium and large municipal separate storm sewer systems (MS4) and eleven categories of industrial runoff including construction that disturbs more than five acres of land (EPA 2003e). Phase II beginning in 1999 addresses smaller MS4s as well as construction activities disturbing between one and five acres of land (EPA 2003e). Phase II also requires Federal, state and military facilities to participate in the permitting program. These programs require local municipalities to manage and maintain a stormwater management program.

NPDES also requires that stormwater management programs address the following six issues: public education, public involvement, illicit discharges, construction site runoff control, post-construction runoff, and pollution prevention (EPA 2000c). How each municipality addresses each issue is not regulated. Even though, the EPA does not set specific pollutant standards, the NPDES permit does not release the municipalities from any other regulator or court ordered actions (Debo and Reese 2003). Therefore, a flexible program allows a municipality to tailor its system for its specific challenges in its area.

The permit must be renewed every five years, which will result in a review of the effectiveness of the stormwater management program.

Phase II also encourages municipalities within close proximity to work together and apply for a general permit (Debo and Reese 2003). This allows municipalities within a watershed to work together and coordinate their collective stormwater program across municipality boundaries. This is especially important for the small MS4s now included because they are located within a large urbanized area. The smaller municipalities can share resources and expertise with the larger municipalities to create a more comprehensive program than may have been possible if they were forced to apply separately.

Local Ordinances

At the local level, municipalities often respond to federal regulations by implementing local ordinances. In the past, municipalities have responded to stormwater management regulations by enacting local ordinances that require detention ponds to control peak flow (Debo and Reese 2003). There have been other paradigm shifts since detention ponds were first utilized to control stormwater runoff primarily as flood control, but many municipalities are still dependent on this engineered, structural solution. There are many policies, both structural and nonstructural, that municipalities are implementing to manage stormwater.

Ultimately, all types of development result in an increase in impervious area. The focus of this paper is large commercial and institutional (federal, state, military, and university) land uses. These types of properties consume large quantities of land and as a result contribute significantly to the stormwater runoff in urban areas. Due the large areas of land that these properties consume, ordinances that require stormwater management on site often result in additional costs for the property owners. Since NPDES Phase II no longer exempts federal, state, and military facilities, these property owners could incur additional stormwater management costs.

The paper focuses on commercial and institutional land uses for multiple reasons. First, these facilities usually have a variety of activities (residential, office, parking etc.) which allows for the implementation of many different methods throughout the system. Secondly, the large facilities would result in a large single (new) cost to the property owner if stormwater utility fees were implemented. Thirdly, these properties have had long-term consistent stable property management that could ensure proper LID implementation and maintenance.

III. LOW-IMPACT DEVELOPMENT

Low Impact Development (LID) is an approach to development that attempts to minimize development's effects on the environment. Although there are many aspects of LID, this paper only addresses issues related to stormwater management. The methods utilized for LID are not, by themselves, new technology and many have been in use for over thirty years (Tunney 2001). LID consists of both structural and non-structural methods that seek to mimic the environment's natural hydrologic cycle. It is the combination of stormwater management methods and the way they are implemented that is new.

Stormwater is part of the hydrologic cycle. There are five main components to the cycle: "precipitation, infiltration, evapotranspiration, surface and channel storage, and groundwater storage" (Lehner et al. 2001). A naturally vegetated environment allows for maximum infiltration and minimizes runoff to surface water or into various forms of storage. Through infiltration, the natural system also recharges groundwater.

Initially pioneered by the Planning Department in Prince Georges' County, Maryland, LID methods are used in different combinations in an effort to primarily reduce impervious area and enhance infiltration (EPA 2000b). The Prince George's County Department of Environmental Resource Programs and Planning developed the design strategies for LID. The methods utilized are termed integrated management practices (IMP) (Coffman 2000). Common structural IMPs include rain gardens and bioretention, roof top gardens, sidewalk storage, vegetated swales, buffers and strips, roof leader disconnection, rain barrels and cisterns, permeable pavers, and soil amendments (Lehner et al. 2001). Non-structural IMPs include: impervious surface reduction and disconnection, pollution prevention, and good housekeeping (Lehner et al. 2001). The effectiveness of the use of IMPs in development is dependent on the coordination of their implementation and the site design. The three main goals of the strategies are: greater groundwater recharge, retention or detention of stormwater for later release or reuse, removal of pollutants through settling and entrapment (Coffman 2000). All IMPs that encourage infiltration also reduce the volume of stormwater.

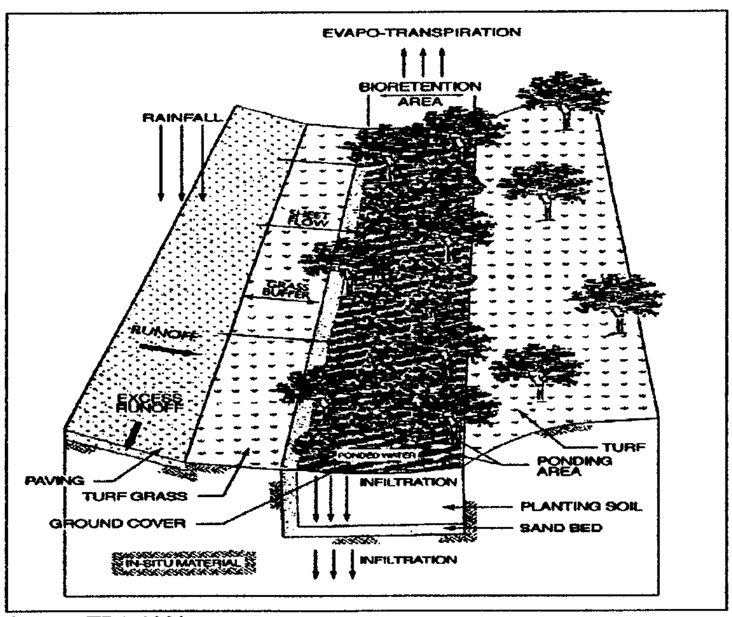
LID represents another shift in the stormwater management paradigm. It incorporates three critical water resource issues: pollution prevention and treatment, flood control, and watershed management. It takes existing technologies and utilizes them in an ecological way to manage stormwater by understanding the relationships between organisms and their environment. The key to LID is the scale. IMPs are designed to be implemented at the parcel level. IMPs also offer opportunities for stormwater reuse, the next potential paradigm shift.

LID is also promoted as a cost effective program. By managing stormwater runoff at the source, cost savings are realized due to reductions in conveyance, storage, and treatment facilities. These costs usually increase with an increase in distance from the source (Coffman 2000). Depending on the method used, runoff can be treated and infiltrated on site or retained for later use.

For the purposes of this paper, three methods are presented as the best potential LID IMPs for implementation for large-scale commercial and institutional land uses. Bioretention, permeable pavements, and rain barrels are the most easily applied methods under redevelopment conditions in urban areas. Together these methods can work together to reduce the effects of development on the environment and restore the natural hydrological cycle. Additional methods include green roofs and development clustering, both intended to reduce the amount of impervious area. However, these two methods are more easily applied under new development conditions.

Bioretention

Bioretention seeks to mimic the natural processes of treating and infiltrating excess water. This method utilizes "soils and both woody and herbaceous plants to remove pollutants from stormwater runoff" (EPA 1999). Figure 2 is an illustration of a typical bioretention cell. Bioretention consists of a vegetated depression area to collect and drain surface runoff. The soil bed consists of a planting soil surrounded by a sand bed. This allows for maximum infiltration. The areas around the bioretention area are sloped to convey runoff to the area. The landscaping of the bioretention area consists of native vegetation that can tolerance both wet and dry conditions. When implementing bioretention on land uses that produce highly polluted runoff such as gas stations, an impermeable liner is required at the bottom of the filter bed to prevent groundwater contamination (EPA 2002b).



Source: EPA 1999

Figure 2: Bioretention Cell

Although there are many benefits to using bioretention, there are several limiting factors, including soil composition and slope. Soils high in clay content have much slower infiltration rates; unstable soils, such as those on extremely steep slopes, may prohibit installation of this method (EPA 1999). An additional mediating factor includes the local climate that may dictate modifications to account for cold and/or arid conditions.

Design size of the retention cell is related to the total amount of area to be drained. As a rule of thumb, the cell area should be approximately five percent of the total area to be drained. This type of system is ideal for small areas, usually less than five acres (EPA 2002b). To drain larger areas, multiple cells must be utilized. Even though this strategy is best utilized at a small scale, it can still be employed in heavily urbanized areas. For example, bioretention can be utilized in urban parking lots where medians and landscaping can be modified to act as retention cells.

The costs of bioretention differ based on land use and the timing of implementation. For commercial, industrial, and institutional uses such as those targeted for this paper, the costs to implement is between $10 to $40 per square foot (2003a). In addition, the cost of implementation depends largely on when the cell is installed. If the system is installed along with new construction or as part of redevelopment, the costs are lower. These systems are ideal for redevelopment projects because, even though the actual cost of additional landscaping and design is initially higher, the overall cost can be mitigated when the system reduces the costs of other stormwater management infrastructure (such as curb, gutter, and drain piping.)

The design of a bioretention cell requires additional prior planning. For example, depending on the site conditions, additional grading may be required to redirect runoff to the cells. In addition, soil information is required prior to design to ensure proper drainage. Further, there are certain sizing considerations and it is based on the total area to be drained. A minimum of 15 feet in width is recommend with a length of 40 feet (EPA 1999). Specific recommendations on the design of a bioretention cell can be found in the *Design Manual for Use of Bioretention in Stormwater Management* by the Prince George's County Department of Environmental Resources (PGCDER).

Maintenance of bioretention cells is minimal. Generally, maintenance involves monitoring, debris removal, re-mulching, and replanting. A maintenance schedule available from PGCDER can be modified based the implementation characteristics of the local application. The most important difference from general landscaping and grounds keeping is that for these systems to function properly it is important that the plant life be maintained according to the initial design.

Bioretention cells have been successful in reducing both runoff volume and pollution particularly that associated with the first inch of rainfall. Generally heavy metals such as copper, lead, and zinc have been removed through bioretention with high success rates (Davis et al. 2003). Bioretention is also effective in reducing concentrations of phosphorus, nitrogen, and calcium (EPA 2002b). Although bioretention, by itself is not designed to provide flood control, channel protection, or groundwater recharge, its use can reduce the volume of runoff conveyed to stormwater systems and can reduce the occurrence of minor flooding due to overflows associated with small storm events. Additionally, bioretention combined with an infiltration trench or basin can assist in groundwater recharge.

Permeable Pavements

There are two primary categories of permeable pavements: porous pavements and alternative pavers. Porous pavements include porous asphalt and pervious concrete (SMRC 2003b). Alternative pavers include paving blocks with grid systems and loose systems such as gravel, mulch, and brick or stone in loose configurations (SMRC 2003a). Both systems provide higher rate of infiltration than is possible with traditional pavement, though the amount of infiltration varies with the type of pavement. Permeable pavements reduce impervious area to allow greater infiltration and to reduce pollutant levels.

These pavements can be utilized throughout the United States with special design consideration in cold climates. The most suitable applications are for low traffic areas, parking lots, and walkways in heavily urbanized areas (SMRC 2003b). Since both types of pavements operate based on void areas utilized for infiltration, they are both susceptible to clogging and must be well maintained. In cold climates, they are not recommended for use in areas that use sand and salt for freezing due to clogging by sand and groundwater pollution from salting (EPA 2002c). Also plowing is not recommended as it can damage the pavements. Although, they are not ideally suited for cold weather climates, with proper maintenance, they can be effective in reducing pollution and runoff volume (EPA 2002c).

Just as bioretention is best suited for pollutant removal and stormwater volume reduction, permeable pavers are also successful in reducing pollution and providing greater groundwater recharge. Studies suggest porous pavements applications can yield as much as 70-80% of annual rainfall as groundwater recharge (EPA 2002c). As such, their applicability is not suggested for land uses with stormwater "hot spots." Stormwater hot spots are areas of high pollutant concentrations including commercial nurseries, auto recycling facilities, fueling stations, or commercial parking lots (EPA 2002c). Although many commercial and institutional land uses, such as university campuses and military bases, have areas that are considered hot spots, the use of permeable pavements is still applicable in other sectors such as residential and administrative facilities.

Costs associated with permeable pavements are highly variable. The costs of materials vary widely, depending on the materials used. Costs for porous pavements and brick/stone pavers are normally much higher than traditional asphalt pavements, while mulching, gravel and cobbles are generally lower in cost (SMRC 2003a). A cost of installation for most alternative pavements is much higher than traditional pavements. Maintenance costs are also higher than traditional asphalt, primarily because maintenance of these pavements is more complicated than traditional asphalt. Porous pavements usually require vacuum sweeping to remove sediment. Loose configuration pavers require more attention to ensure they are not clogged and to ensure they are still intact (SMRC 2003a).

The key to successful alternative pavements is the implementation of a detailed site-specific maintenance plan. In addition, a training program for maintenance personnel on the different aspects of the facilities is recommended. Without a maintenance plan and well-trained staff, alternative pavement solutions will be less effective in reducing runoff.

Rain Barrels and Cisterns

Rain barrels are used to store stormwater for reuse and ultimately assist with infiltration. A typical installation captures roof runoff. The runoff can then be utilized for irrigation (Coffman 2000). Although often utilized in residential applications, they can be designed for larger scale requirements using cisterns. Cisterns are often placed underground and provide a larger capacity (Coffman 2000).

Implementation of rain barrels and cisterns is feasible across the United States although there may be some additional requirements for use in cold weather climates to ensure that the system does not freeze and damage the storage containers. Additionally, the systems must be equipped with proper hoses and locks to ensure safety. Since the system does not provide treatment, the system should not be utilized as a source of drinking water and every precaution must be taken to ensure human ingestion cannot occur (Coffman 2000). Overall, this system is much less expensive than the previous IMPs; but, it also provides far less capacity than either bioretention or permeable pavements. Rain barrels are less costly than cisterns because they do not require excavation. Although cisterns are more expensive to install, they provide greater capacity and can be utilized to augment irrigation for a larger area due to the increased capacity.

There are many more IMPs in the LID toolbox but the three described above have the most potential for implementation in the focused land uses of this paper. These IMPs can also work in conjunction with each other to provide a more effective runoff treatment system.

IV. LID URBAN AREA CASE STUDIES

Although many of the first examples of LID in practice are located in Prince George's County, Maryland, all of the methods proposed in this paper have been implemented in other areas of the country. To examine the actual application of these LID methods in commercial and institutional settings, three case studies are presented. The following examples were selected because they reflect a cross-section of plans being implemented in urban areas.

Washington Navy Yard, Washington DC

The Washington Navy Yard (WNY) is a military installation managed under the regional command of Naval District Washington (NDW). WNY is 204 years old and is the "oldest naval shore facility" (LANTOPS 2003). The installation is located in southeastern Washington D.C. on the Anacostia River, which feeds into the Potomac River. The area is within the Chesapeake Bay watershed. Throughout its history, the mission of WNY changed from industrial manufacturing of guns and ordinance to its current mission which is primarily administrative. Most facilities on the base have been renovated into office space. In the late 1990's the U. S. Navy embarked on an effort to consolidate administrative functions of multiple installations in concentrated areas under a regional management organization.

A regional management organization, the Naval District Washington (NDW) was formed in 1999. The NDW consists of eight individual installations including the WNY and additional facilities are expected to be included in the near future. Regionalization is ultimately an effort to reduce administrative infrastructure and utilize resources in a more efficient manner. Instead of having separate management processes and organizations on each individual base, a regional organization manages all the bases from a central management structure. For example, environmental programs are now coordinated across all eight installations in the region instead of independently.

In 1998, the WNY was designated a superfund site and the U. S. Navy, the EPA, and the District of Columbia agreed to a Federal Facility Agreement (FFA) which outlines the procedures to be undertaken to clean up the facility (LANTOPS 2003). One important aspect to the clean up efforts was the rehabilitation of the storm sewer system. Much of the six mile system was more than 160 years old and required extensive repair (EPA 2000b).

The WNY itself is 71 total acres, of which 60 acres are impervious. The resulting percentage of impervious area is 85 percent, is even higher than the District of Columbia which is 65 percent impervious (Lehner et al. 2001). Therefore, the volume of runoff that the stormwater system manages is considerable.

In conjunction with the repairs on the drainage system, the NDW Environmental Department began a demonstration LID program to evaluate ways to reduce runoff volume and pollution. The program includes 10 projects utilizing bioretention, rain barrels, and permeable pavers throughout the WNY (Lehner et al. 2001). These projects are being monitored to demonstrate the effectiveness of these methods in an urban environment.

Although empirical data is not yet available, NDW's has already learned from the experience with the LID program. At this point, the lessons learned are more administrative than technical and are valuable in terms of applying the LID methods to similar land uses. One particular problem, which the NDW has experienced, relates to contracting for maintenance of the LID projects. Three issues have emerged. Most contractors lack the knowledge and expertise to maintain these facilities. Second, since there are so few sites, many contractors are not interested in learning new skills. Finally, there are no specific details available to set up an appropriate maintenance schedule (Grigg 2003). Each issue is presented in more detail below.

The knowledge and expertise for the care and maintenance of an LID test site was not within the knowledge, skills, and abilities of this current landscape maintenance contractor. NDW explored the possibility of an education program for the current contractor, but determined that it would be too costly because of a high rate of employee turnover for the current contractor (Grigg 2003). Therefore, NDW plans to sign a new separate contract for the maintenance of the test LID sites for an organization specifically identified with the appropriate skills.

During the process of putting together the specification for a new contract to maintain just the LID sites, NDW encountered two other issues. With only 10 sites, the new contract appears to be a small dollar value contract that requires specialized knowledge (Grigg 2003). This could result in too few bidders for the competition requirement for federal contracting.

In addition to the size of the contract, LID methods are still new and the maintenance schedule is not easily specified. Although Prince George's County offers advice on a typical maintenance schedule for different LID methods, they often rely on maintenance on an "as needed" basis which can vary from monthly to yearly (LID Center 2003b). Since maintenance is largely a function of the amount of pollutants, rainfall volume, and the hydrology of the site, the maintenance schedule must be site specific. Therefore, since these methods are still new and lack site specific data, the maintenance contract will need to be modified as additional information is gained both from the NDW sites themselves and others like them. As the methods are researched, additional information will be available to assist property owners in maintaining these systems.

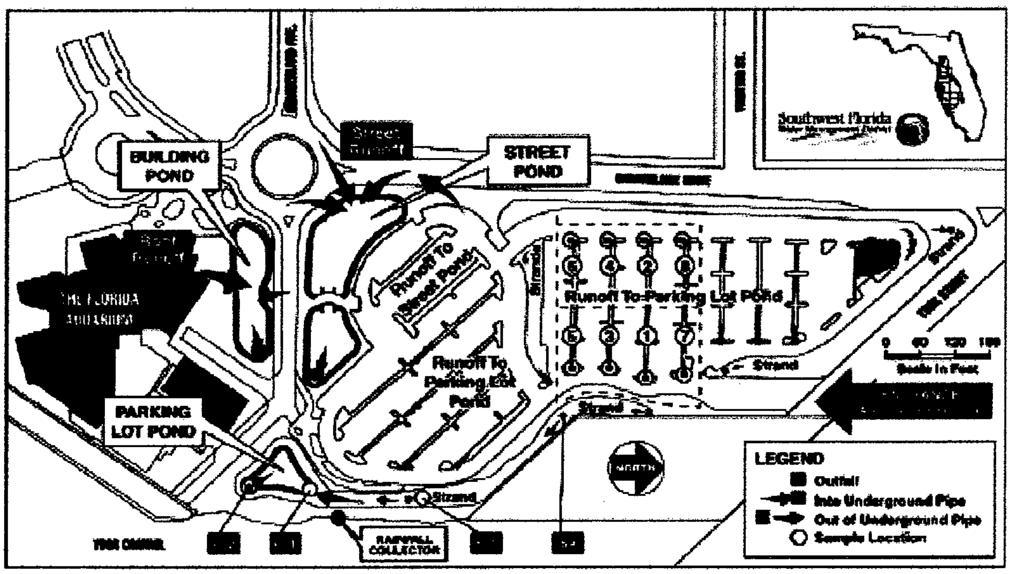
Even though the projects have run into maintenance contractual issues, NDW has plans to build additional projects at other installations in the region. They are committed to LID as a means to improve the hydrology of naval installations. In fact, the U.S. Navy is drafting the Low Impact Development Design Manual for future implementation of LID at all naval installations.

Florida Aquarium, Tampa FL

The Florida Aquarium is a 152,000 square foot facility in Tampa, FL that opened in 1995 (Jackovics 2002). Since its opening, the aquarium has changed hands to city ownership when it failed to become financially stable. The city hired a new director who has increased visitation rates at the aquarium. Although it has not yet reached its anticipated goal of 1.8 million visitors a year, more than 550,000 people visit the aquarium each year (Schaffer 1995). Consequently, over 11 acres of the facility is dedicated to parking.

The aquarium is located within the Southwest Florida Water Management District (SWFWMD), which is one of five water management districts in Florida. The water management districts are responsible for water supply conservation and allocation, water quality, flood protection, and natural systems management (Purdum 2002).

Runoff from the aquarium discharges into Tampa Bay. Tampa Bay is an Estuary of National Significance and is part of the EPA's National Estuary Program (NEP) (Rushton 2002). The NEP mission is to develop plans to attain and maintain water quality in the nation's estuaries (EPA 2003b). The Tampa Bay NEP addresses six priority management issues: nutrients, toxics, habitat loss, species loss and decline, freshwater inflow and sedimentation (EPA 2003c). In general, the Tampa Bay NEP is focusing on reducing stormwater runoff that is directly discharged into the bay.

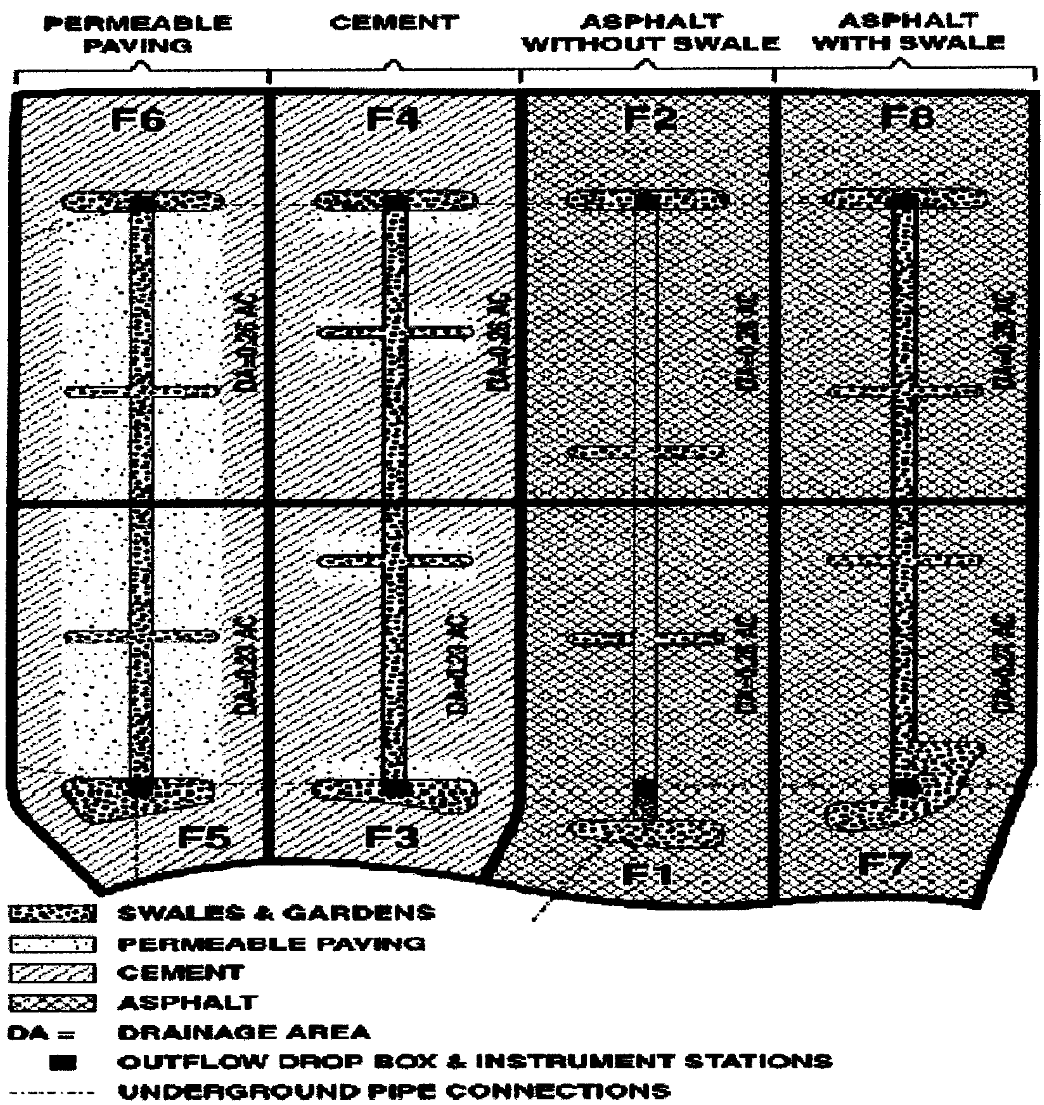


Source: Rushton 2002

Figure 3: Florida Aquarium Site Plan

Since the aquarium was initially a non-profit facility with an initial vision to focus on environmental education, the parking lot became a demonstration and education site for stormwater management. Parking lot test cells were built utilizing vegetated swales and permeable pavements (see Figure 3). The SWFWMD utilized the site as a demonstration site for research on these LID methods. In 1998 and 1999, SWFWMD collected data from the site to determine the effectiveness of the different LID IMPs (Rushton 2002).

As shown in Figure 4, the parking lot was designed to test three different LID conditions. The control was the asphalt without a swale condition. Other conditions tested were asphalt with swale, concrete with swale, and permeable pavement and asphalt with swale. This study allowed the researchers to compare pavement types and the use of bioretention swales in runoff reduction and pollution mitigation. Additional swales are located on the perimeter of the parking lot and drain to wet ponds.



Source: Rushton 2002

Figure 4: Florida Aquarium Parking Lot Site Plan

Table 2: Pollutant Reduction at the Florida Aquarium

Constituents	Percent pollutant reduction[a]		
	Asphalt w/swale	Cement w/swale	Porous w/swale
Ammonia	45	73	85
Nitrate	44	41	66
Total Nitrogen	9	16	42
Orthophosphorus	-180	-180	-74
Total Phosphorus	-94	-62	3
Suspended Solids	46	78	91
Copper	23	72	81
Iron	52	84	92
Lead	59	78	85
Manganese	40	68	92
Zinc	46	62	75

[a]The basins with swales were compared to a basin without a swale to determine the amount of reduction in pollutant loads possible using these small alterations. Notice that the efficiencies for phosphorus are negative, indicating an increase in phosphorus load in the basins with a swale.
Source: EPA 2000a

The research findings indicate that the best condition in runoff reduction and pollution reduction was the permeable pavement and swale condition. Runoff volume for the permeable pavement condition was reduced to 16% of the maximum volume versus 30% with asphalt with swale or concrete pavement with swale. The same system also reduced the pollutant load by more than 90% (Rushton 2002). Pollutants most effectively removed were ammonia, nitrogen, copper, iron, lead, manganese, zinc and suspended solids. Decreases in pollutant loadings varied depending on the pollutant (EPA 2000a). See Table 2 for the breakdown of pollutant reductions by pollutant.

As a large municipal land use, the Florida Aquarium is ideal for LID IMPs because of the large area required for parking. As a whole, the facility retained 99% of the runoff on site. Therefore, this study demonstrates that these methods can reduce the volume of stormwater runoff that would have gone directly into Tampa Bay.

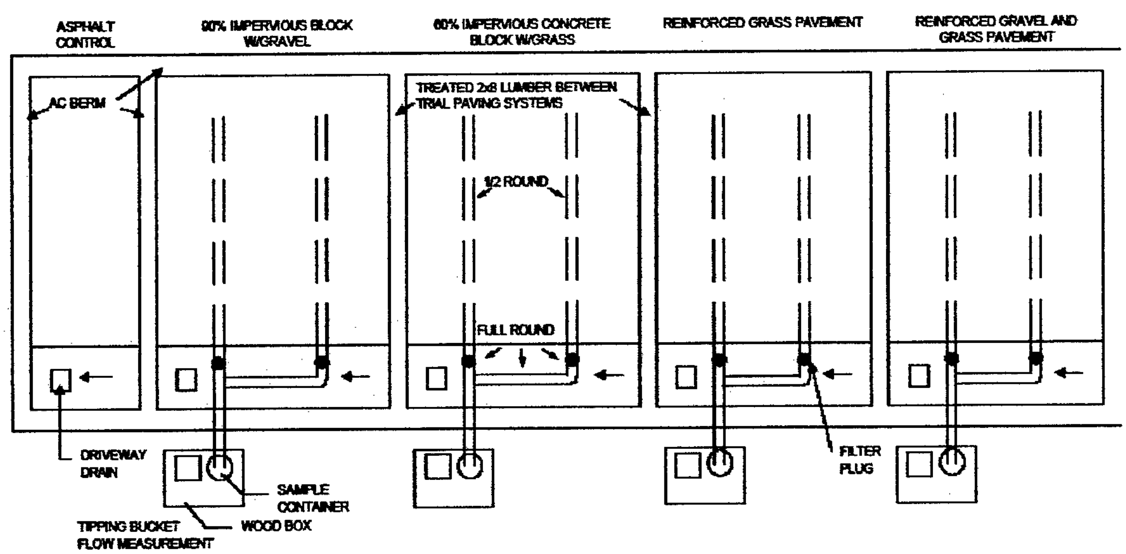
Since the completion of the study in 2000, it appears that the facility has not been maintained properly. The author of the study, Dr. Betty Rushton, observed both newly planted trees and bushes in the swales and landscape personnel blowing leaves down the storm drains (2003). This clearly demonstrates the need for education about these facilities. The maintenance of the system must be done correctly and consistently to ensure proper functioning. In other words, the system must be maintained as a stormwater system and not just as landscaping. Therefore, the ground maintenance team whether in-house or contracted, must be educated on the proper maintenance of the system. This is especially significant with respect to removal of sediment and replanting of vegetation.

In addition to education of the landscape maintenance personnel, it is also important for the property owners to be properly educated about these systems. This could be difficult if the property ownership changes hands often. Although aquarium ownership changed hands prior to the installation of the test sites, management of the facility is expected to change hands again as the aquarium looks for a new director (Jackovics 2002). The ownership change did not affect the project directly, but multiple ownership changes could endanger innovative systems like these because the system may not appear different to the untrained eye.

Multiple changes in ownership create a barrier to LID IMP implementation. This would be negative factor to endorsing these systems in commercial properties where ownership can change often. For example in Houston, Texas, a medical office building was developed with an innovative stormwater management system (Sorvig 2002). The system created a functional open space that disguised the stormwater detention system. When the facility was sold shortly after construction finished, the detention system was chlorinated and no longer open to the public (Sorvig 2002). The remedy to this problem may lie in a formal restriction, such as an easement, to be attached to the property so that when the property changes hands these systems are not lost in the transition.

King County Public Works Facility, Renton, WA

The King County Public Works facility in Renton, Washington is another demonstration project, comparing different types of permeable pavements. The test site was constructed in 1996 on a portion of the employee parking lot. The project was designed as a controlled field test to evaluate the effectiveness of four different systems: grid with grass, and grid with gravel filled cells, both with virtually no impervious surface; and two impervious pavers systems with 60% and 90% impervious surface respectively (Brattebo and Booth 2003). The control situation was traditional asphalt pavement. Figure 5 represents the test site configuration.



Source: EPA 2000a

Figure 5: King County Public Works Permeable Pavement Field Test Site Layout

The test site has been active for seven years and has continued to function as an employee parking area for the King County Public Works Department. An initial study of runoff was conducted in 1999, again in November 2001, and from January to March 2002 (Booth et al. 2003). Runoff from the cells with permeable pavement was virtually eliminated in comparison to the asphalt control cell even though each permeable pavement system had varying amounts of imperviousness. In addition to reducing runoff, the study further indicates that each permeable pavement system also reduced the levels of copper and lead in runoff compared to the asphalt control cell. The grid systems performed better than the concrete paver systems in reducing pollutant loading. (Booth et al. 2003).

V. ENCOURAGING LID

Today, stormwater management is an expensive issue for municipalities. For example, the City of Atlanta, GA, which operates a CSS, is planning to build a super combined sewer at the cost of $3 billion to combat its stormwater problems. To pay for this massive project water and sewer rates may triple from $60 per month to $172 per month after five years (Bennett and Shelton 2003). Many communities are facing similar problems. There are over 770 communities across the U. S. that also have CSS systems (EPA 2002a).

Obstacles

Traditional solutions of conveyance and storage are not efficient methods in the face of greater development and increases in impervious area. For example, pipe systems and detention ponds merely delay the runoff before releasing it directly into receiving waters. Utilizing LID methods can reduce the quantity of stormwater by mimicking the hydrologic cycle, which in turn improves the quality of the runoff and the receiving waters. If LID methods are implemented on a larger, watershed scale, they could assist municipalities in managing stormwater more efficiently. Therefore, costly drainage and storage systems could be avoided.

The implementation of LID has three major obstacles to overcome: (1) unproven/unfamiliar technology, (2) cost, and (3) municipal regulatory requirements. First, the technology may be considered unproven and/or unfamiliar. Any new or unfamiliar technology is often accepted slowly. Most LID implementation sites are considered demonstration sites, even though some may be more than ten years old. Therefore, greater visibility through educational programs and site visits could lead to greater acceptance and implementation of LID.

The second obstacle is cost (or at least the perceived cost) of LID methods, even though LID proponents claim that both short term and long-term cost savings are a primary benefit to LID. Stormwater management costs are born both by the property owner and by the municipality. Property owners bear the initial construction costs and subsequent maintenance costs. Municipalities bear the long-term conveyance, storage, and potential treatment costs of stormwater that is not managed on site. In addition, the types of stormwater management methods allowed are dictated by the municipality. Therefore, to incorporate LID the method, first, must be an accepted practice for stormwater management by the municipality and, secondly, it must be cost effective for the property owner to install.

Since short-term construction costs are often the most expensive and the most visible to property owners, it is important to educate property owners on the costs savings that can be generated from LID methods. For example, the Oregon Museum of Science and Industry was recently redesigned using LID methods. Specifically, the parking lot was redesigned to facilitate stormwater drainage to bioretention swales in the medians versus a convention stormwater system. The redesign resulted in a construction cost savings of $78,000 (see the Appendix), yet it did not affect the construction schedule of the capacity of the parking lot (Clarke and Stoner 2001). Other LID projects may result in higher initial costs than with conventional systems, but show reduction in long-term costs.

The long-term cost savings are more indirect. Property owners can save in maintenance costs and municipalities generate cost savings in stormwater conveyance and environmental clean up at discharge locations. By reducing both the pollutant loading and the volume of stormwater that discharges to a sewage treatment plant or directly into receiving water, municipalities can avoid costs for clean up in the future. Ultimately implementation costs are the burden of the individual property owner whereas treatment and clean up costs are municipal costs. Therefore, incentives to property owners directly, such as abatement credits, could be utilized to encourage property owners to implement LID.

Although costs for the implementation of the field study cases are not available, other applications have resulted in substantial savings for the property owner usually in construction costs. The cost savings for municipalities is not yet available, but could be calculated based on the cost of treatment per volume of stormwater for municipalities with combined systems. For municipalities with separate systems that do not treat the effluent, the savings are intangible and are related to the decrease in pollution and erosion. Ecologically, the habitat of the receiving waters will receive lower impact and costs of future clean up could be mitigated.

Lastly, implementation of LID is often impeded by the local ordinances and the zoning processes. Rigid ordinances, which have specific requirements with respect to street design, stormwater drainage retention, lot setbacks, and other regulations, can hamper implementation of LID. The success of LID will depend largely on the flexibility of the municipality in allowing their implementation. Most often, even communities that want to implement these methods have a regulatory environment that requires more approvals for these innovative designs when compared to the traditional designs (Lehner et al. 2001). Therefore, the first thing that municipalities must do is create a local regulatory environment that supports the implementation of LID through flexible ordinances and permit streamlining.

Stormwater Utility

Ultimately, it is the municipality's responsibility to create and maintain the stormwater management program as required NPDES. Unfortunately, the federal government does not provide funding directly for NPDES or the subsequent stormwater management programs permitted (Debo 2003). As such, many communities are seeking funding sources for these programs. One such funding source would be to establish a stormwater utility that charges a fee to all property owners to support the stormwater management program.

A stormwater utility is a fee-based program that applies a user fee to property owners. The utility operates like water, sewer, and electric utilities with one important distinction stormwater utilities charge fees to create revenue to help manage stormwater (Kaspersen 2000). As such, a stormwater utility typically charges property owners not for the use of a service or product but rather on the estimated stormwater their property contributes to the overall level of stormwater and its related management in an area. Since the amount of impervious surface is strongly related to stormwater runoff, most stormwater utilities utilize an impervious area calculation for the basis for their utility rates (Debo and Reese 2003). Therefore, a reduction in impervious area would translate into a decrease in the cost of stormwater management and a resultant decrease in a stormwater utility fee.

Stormwater utilities are important for two major reasons. First, the utility is a fee-based program rather than a property tax program per se. Therefore, the land uses discussed in this paper, which are often exempt from property taxes, are not automatically exempt from fees. For example, federal and state properties are exempt from property taxes but are not automatically exempt from service fees. As previously mentioned, the institutional land uses discussed in this paper could incur significant additional costs if a stormwater utility were implemented in their area.

Secondly, NPDES Phase II now regulates more MS4s, which places a greater burden on an already stretched municipal budget. As such, more municipalities are seeking alternate and consistent forms of funding for stormwater management using stormwater utilities. The first stormwater utilities were formed in the 1970's and as of the year 2000, there were more than 400 stormwater utilities in existence nationwide (Kaspersen 2000).

LID Implementation and Stormwater Utilities

With the implementation of a stormwater utility, a master stormwater plan is often an important part of the overall stormwater management program. If the program manages a watershed and has a clearly defined master plan, it is possible to offer incentives to property owners through a credit system. With a master plan, the incentives are tailored in a way to encourage more efficient stormwater management as close as possible to the source. Depending on the goals of the stormwater management program, property owners could be given a credit to their stormwater utility fee for both structural and non-structural management practices implemented on the site. This requires that each property owner who applies for a credit will need to demonstrate that stormwater runoff from the property is treated, detained, or otherwise diverted from the municipal stormwater management system. Therefore, LID implementation could be facilitated by assisting property owners that employ these methods by reducing the stormwater utility fee. For an example of this option, see the Appendix, which calculates the utility fee savings for a parking lot with a bioswale.

All of the case studies were located in areas that either have a stormwater management utility fee (King County and Washington D.C.) or are in the process of implementing a fee (Tampa) (Lehner et al. 2001; Salmon 2003; Woodworth Jr. et al. 2002). Therefore, continued implementation of LID methods in these areas will likely be dependent on the way the utility fees are assessed. If the utility does not reduce fees for implementation of LID, property owners within those communities will have little incentive to either maintain the existing sites or install more.

Now that most municipalities are regulated through NPDES and more stormwater utilities are implemented as a funding program for stormwater management, property owners will be looking for methods to reduce their impervious surface and ultimately their stormwater fee. It is also in the best interest of the municipality to offer credits for property owners to encourage the use of these methods, even though it decreases the amount of revenue the stormwater utility receives. It is more costly to treat the stormwater at the end of pipe, particularly if the system is a combined sewer system where the treatment facility is designed for sewage treatment, not stormwater treatment. Therefore, the municipality looses revenue from the stormwater credit but saves money by treating less at the end of the pipe.

Future of Environmental Regulation

There is one additional challenge to LID implementation. The federal regulatory environment has changed with changes in our national leadership. Many of the policies that would provide a favorable setting for LID are currently being challenged and weakened by recent proposals from the executive branch (Stoner 2002). Without federal sponsorship of environmental policy that encourages innovation, the implementation of LID will be left up to the local municipalities. Therefore, it will be more important than ever to promote LID and educate both citizens and public official about the benefits of LID.

VI. CONCLUSION & RECOMMENDATIONS

The case studies reviewed above indicate that LID methods can be implemented in urban locations. The results of the field studies suggest that bioretention and permeable pavements are successful in reducing runoff and pollutant loadings. Although, data on the rain barrel implementation at the WNY is not available, they have been successfully implemented in residential applications in the Cities of Toronto and Ottawa (Hager 2003).

In 2002, the Natural Resources Defense Council (NRDC) conducted a study to determine how LID methods could be implemented throughout Washington, D.C. (Woodworth Jr. et al. 2002). Overall, the suggestions to encourage LID in Washington, D.C. are the same as stated previously: utilize the stormwater utility to encourage implementation through promotion of LID demonstration projects, incorporating incentives into the utility fee structure, and ensuring planning and permitting processes are modified to afford the flexibility needed to implement LID.

In order to encourage this level of implementation of LID, continued education and advertisement of LID method is required. Such recommendations include cost benefit analysis brochures that fully disclose construction and maintenance costs and potential utility fee savings for property owners. Another suggestion is clearly identifying facilities to facilitate education of the end users such as employees and visitors.

At OMSI, the stormwater management facility is also an exhibit for the visitors to the museum marked with placards that identify the system and explaining how it works. Similar educational tools could be used at the Florida Aquarium.

Table 3 summarizes the types of information that could be provided in these educational materials for the three LID methods analyzed in this paper. This table provides the type of information needed by large commercial and institutional property owners to answer critical questions and reduce. Ultimately, the only way to encourage the use of LID is better education of property owners, developers, and municipalities.

Table 3: Summary of LID Methods

Method	Key References	Applicability	Stormwater Impacts	Cost Compared to Traditional Methods		Maintenance Issues
				Initial[1]	*Long-term*	
Bioretention:						
Bioretention cells & Rain Gardens	Coffman 1999	Parking lots, Street medians, Swales	velocity reduction, pollutant reduction, volume reduction[2]	Higher	Variable	Biannual evaluation Replanting as needed
Permeable Pavement:						
Pavers, concrete,	SMRC 2003	Walkways and parking lots	velocity reduction, pollutant reduction, volume reduction	Higher	Lower	Vacuum sweeping (4 times/year) or low-pressure washing
Concrete grids with grass/gravel	SMRC 2003	Parking lots	velocity reduction, pollutant reduction, volume reduction	Higher	Lower	Watering and mowing for grass
Porous concrete	SMRC 2003	Parking lots	velocity reduction, pollutant reduction, volume reduction	Higher	Lower	Vacuum sweeping
Rain Collection:						
Rain Barrels	NAVFAC 2003	Roof Runoff of: small buildings: ex: residences	Volume Reduction	Lower	Variable[3]	Safety inspections at least twice a year
Cisterns	NAVFAC 2003	Roof top runoff of medium to large buildings	Volume Reduction	Higher	Variable[3]	Safety inspections at least twice a year

Notes:

1. Does not account for savings that may be achieved from the elimination of curb, gutter and other drainage systems
2. With infiltration trench
3. If water is expensive, collected rain water can supplement irrigation

APPENDIX

Sample Cost Savings Calculation

The Oregon Museum of Science and Industry (OMSI) saved $78,000 through the redesign of a six-acre parking lot. The bioswales used in the medians utilizes approximately five percent of the total area. With reduced construction in those swales, total construction costs went down $ 78,000 (Clarke and Stoner 2001).

In addition to the initial construction cost savings, the OMSI may be eligible for a stormwater utility credit. The City of Portland, Bureau of Environmental Resources is in the process of implementing a discount credit for stormwater management practices such as that constructed at OMSI (Bureau of Environmental Resources 2003). Based on the current stormwater utility rate for commercial property of $5.17 per 1000 sq.ft. of impervious area, OMSI is currently paying $16,215 per year for stormwater management. The improvements at OMSI will likely qualify for the reduced rate, which will be implemented by fiscal year 2006. The stormwater rate is expected to increase to $8.80 per 1,000 sq.ft. but the discounted rate is only $5.93 per 1,000 sq.ft. (Bureau of Environmental Resources 2003). By 2006, OMSI would save approximately $9,000 per year in stormwater utility fees, see Table 4.

Table 4: Sample Calculation of Possible Stormwater Credit

Example (A): Six-acre parking lot; (B) 5% of total parking area in bioswales. **Note Utility fee reduction occurs in 2006 and beyond**					
Construction Costs	Cost per SQFT	Total Parking Area (SQFT)	Cost	Total Cost (000)	**Construction Savings**
A: Traditional Landscaping	$16	261360	$4,181,760	$4,181,760	
B: Bioswales (5%)	$10	13068	$130,680		
	$16	248292	$3,972,672	$4,103,352	**$78,408**

Utility Fees	Fee (per month/ 1000 sqft)	1000 sqft	Monthly Cost	**Annual Savings**
FY 2003				
A: Traditional Landscaping	$5.17	261.36	$1,351	
B: Bioswales (5%)	$5.17	261.36	$1,351	**$0**
FY 2006				
A: Traditional Landscaping	$8.80	261.36	$2,300	
B: Bioswales (5%)	$5.93	261.36	$1,550	**$9,001**

The fee is not credited completely because very large rain events will still discharge runoff to the municipal storm system through overflow devices. Other commercial and institutional facilities can clearly save construction costs and benefit from stormwater utility credits. In Portland, additional savings could be available because the stormwater credit system will also provide retroactive credits to those facilities that implement onsite stormwater management before 2006.

REFERENCES

Bennett, D. L. and S. Shelton (2003). Sewer bills likely to triple in 5 years. Atlanta Journal-Constitution. Atlanta.

Booth, D. B., et al. (2003). The University of Washington Permeable Pavement Demonstration Project - Background and First-Year Field Results. Seattle, Center for Urban Water Resources Management, Department of Civil Engineering, University of Washington.

Brattebo, B. O. and D. B. Booth (2003). Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. Seattle, Center for Water and Watershed Studies Department of Civil and Environmental Engineering, University of Washington.

Bureau of Environmental Resources (2003). Retroactive Stormwater Discounts - Council Decisions and Estimated Impacts, City of Portland, Bureau of Environmental Resources.

Clarke, G. A. and N. Stoner (2001). "Stormwater Strategies: The Economic Advantage." Stormwater: The Journal For Surface Water Quality Professionals **2**(1).

Coffman, L. (2000). Low-Impact Development Design Strategies, An Integrated Design Approach, Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division.

Davis, A. P., et al. (2003). "Water Quality Improvement Through Bioretention: Lead, Copper, and Zinc Removal." Water Environment Research **75**(01): p. 73-82.

Debo, T. N. (2003). Personal Communication.

Debo, T. N. and A. J. Reese (2003). Municipal Stormwater Management. Washington, DC, Lewis Publishers.

EPA, U. S. (1999). Storm Water Technology Fact Sheet - Bioretention. Washington Dc, U. S. Environmental Protection Agency, Office of Water.

EPA, U. S. (2000a). Bioretention Applications: Inglewood Demonstration Project, Largo Maryland, Florida Aquarium, Tampa, Florida. Washington, DC, U. S. Environmental Protection Agency, Office of Water.

EPA, U. S. (2000b). Low Impact Development (LID); A Literature Review. Washington, DC, U. S. Environmental Protection Agency, Office of Water and Low Impact Development Center.

EPA, U. S. (2000c). Storm Water Phase II Final Rule: Small MS4 Storm Water Program Overview. Washington, DC, U. S. Environmental Protection Agency, Office of Water.

EPA, U. S. (2002a). Combined Sewer Overflows Demographics, U. S. Environmental Protection Agency. **2003**.

EPA, U. S. (2002b). Post-Construction Storm Water Management in New Development and Redevelopment: Bioretention, U. S. Environmental Protection Agency, Office of Water. **2003**.

EPA, U. S. (2002c). Post-Construction Storm Water Management in New Development and Redevelopment: Porous Pavement, U. S. Environmental Protection Agency, Office of Water. **2003**.

EPA, U. S. (2003a). Managing Urban Runoff Point No. 7. Washington, DC, U. S. Environmental Protection Agency. **2003**.

EPA, U. S. (2003b). National Estuary Program, U. S. Environmental Protection Agency. **2003**.

EPA, U. S. (2003c). National Estuary Program, Program Profiles, Tampa Bay, U. S. Environmental Protection Agency. **2003**.

EPA, U. S. (2003d). Nonpoint Source Pollution: The Nation's Largest Water Quality Problem, U. S. Environmental Protection Agency. **2003**.

EPA, U. S. (2003e). Phases of the NPDES Storm Water Program, U. S. Environmental Protection Agency, Office of Water. **2003**.

Grigg, K. (2003). Naval District Washington, Environmental and Safety Department. Washington D.C.

Hager, M. C. (2003). "Low-Impact Development." Stormwater: The Journal For Surface Water Quality Professionals **4**(1).

Jackovics, T. (2002). Florida Aquarium Struggles to Build Attendance, Live Up to Its Name. Tampa Tribune (FL).

Kaspersen, J. (2000). "The Stormwater Utility: Will It Work in Your Community." Stormwater: The Journal For Surface Water Quality Professionals **1**(1).

LANTOPS (2003). Washington Navy Yard, Atlantic Division, Naval Facilities Engineering Command. **2003**.

Lehner, P., et al. (2001). Stormwater Strategies: Community Responses to Runoff Pollution, Natural Resources Defense Council.

LID Center (2003a). Bioretention Cell Costs, Low Impact Development Center, Inc. **2003**.

LID Center (2003b). Bioretention Maintenance, Low Impact Development Center, Inc. **2003**.

NAVFAC (2003). Unified Facilities Criteria (UFC) Final Draft Design: Low Impact Development Manual. Washington D.C., Department of Defense.

Purdum, E. (2002). Florida Waters: A Water Resources Manual from Florida's Water Management Districts. Tallahassee, Florida.

Rushton, B. (2002). Enhanced Parking Lot Design for Stormwater Treatment. 9th International Conference on Urban Drainage, Portland, Oregon, Southwest Florida Water Management District.

Rushton, B. (2003). Personal Communication.

Salmon, M. R. (2003). Memorandum: Stormwater Summary, City of Tampa, Florida Stormwater Department. **2003**.

Schaffer, A. (1995). Florida Aquarium expects 1.85 million attendance in first year. Amusement Business, VNU eMedia, Inc. **107:** 18.

SMRC (2003a). Better Site Design Fact Sheet: Alternative Pavers, Stormwater Manager's Resource Center. **2003**.

SMRC (2003b). Stormwater Management Fact Sheet: Porous Pavement, Stormwater Manager's Resource Center. **2003**.

Sorvig, K. (2002). "From covert to overt: a Houston clinic uses stormwater detention to make a beautiful environment - despite resistance." Landscape Architecture **92**(5): 66-73.

Stoner, N. (2002). Clean Water at Risk: A 30th Anniversary Assessment of the Bush Administration's Rollback of Clean Water Protections. Washington D.C., Natural Resources Defense Council, Clean Water Network.

Tunney, K. W. (2001). "Stormwater Innovative Design: The Role of the Landscape Architect." Stormwater: The Journal For Surface Water Quality Professionals **2**(1).

Woodworth Jr., J. W., et al. (2002). Out of the Gutter, Reducing Polluted Runoff in the District of Columbia. Washington, D.C., Natural Resources Defense Council.