GREEN SITE DESIGN: STRATEGIES FOR STORM WATER MANAGEMENT

Edward A. Cook[1]

INTRODUCTION

Increasingly, proponents of green building are realizing the potential of green site development strategies on the future sustainability of urbanized areas. In particular, alternative strategies for stormwater management are being implemented and show significant promise (US EPA 2003). As the global population becomes more urban, the increase of impermeable surfaces has deleterious effects on water quality and amounts of urban runoff. Traditional approaches to development and stormwater management have resulted in stormwater systems becoming a rapid conduit for delivery of contaminated runoff to rivers and streams. Volumes have increased, concentration times reduced, and natural filtering processes have been bypassed. The result is increased flooding, polluted rivers and streams, health threats, habitat degradation, and increasing expense to maintain inadequate systems. Many municipalities and other government agencies in the US and abroad are attempting to address this issue through regulation and incentive. The United States Green Building Council LEED system recognizes and addresses this problem and the potential for more sustainable stormwater management practices.

The benefits of green stormwater management strategies vary depending on the circumstances of each condition, but examples of lower cost and environmentally superior approaches are found in cities in the US and around the world. Integrating green strategies into new development projects, from planning stages through implementation, is the most cost effective and yields the most efficient and beneficial systems. Retrofitting existing stormwater management systems in cities can be more costly and provide more limited environmental benefits, but antiquation of existing systems creates opportunities to adapt and include green strategies as systems are rebuilt, updated, and improved (Kloss and Calrusse 2006).

It is best to think of green stormwater management strategies holistically, allowing the most efficient opportunities for integration of techniques into the planning, design, and implementation process. These approaches are sometimes represented as green infrastructure (Dunn and Stoner 2007). They are cost effective, sustainable, and environmentally friendly. In general, green infrastructure uses natural systems to the greatest extent possible, but also uses engineered systems that mimic natural systems to collect, treat, and reduce stormwater runoff using plants, soils, and microbes. At broader scales, green infrastructure can consist of a set of connected natural and human-created open space elements that may include forests, flood plains and riparian corridors, wetlands, parks, and more. In addition to the stormwater management benefits provided, recreational activities and wildlife habitat are often accommodated.

PLANNING STRATEGIES

Undeveloped sites often have natural features that can provide environmental, recreational, and aesthetic benefits. Many projects are now employing conservation planning strategies that integrate various site functions that would in traditional projects require conventional infrastructure. In a natural setting, wetlands, streams, rivers, and floodplains perform the functions of collecting and filtering runoff. When planning for new development, effective analysis to identify and understand natural systems can facilitate the integration of drainage systems. These areas are often best considered as part of a multiple use open space system that may provide space for trails, bike paths, wildlife habitat, aquifer recharge, and scenic quality, as well as accommodating stormwater. They can also be marketed as amenities. Figure 1 shows a natural drainage system integrated into a new master planned residential community at Anthem, north of Phoenix, Arizona. It retains its natural drainage functions, but also provides addi-

[1]Associate Professor, School of Architecture and Landscape Architecture, College of Design, Arizona State University, Tempe, Arizona, USA 85287-1605, edward.cook@asu.edu.

FIGURE 1. Natural drainage corridor at Anthem, north of Phoenix, Arizona.

tional benefits of wildlife habitat, separation and buffering of residential areas, recreational opportunities, and aesthetic appeal. Recent research has shown that developments integrating natural open space are experiencing increased property values.

Natural area protection need not be limited to undeveloped sites. Redevelopment projects may also have the potential to include open space, riparian areas, or even some sensitive habitat areas that could be recognized and included in the planning process. In addition, studying natural systems and designing new stormwater systems that mimic the efficient methods of stormwater control and treatment is becoming a more widely accepted approach. Many recent examples now exist that use lessons from nature to assist in the design process. In some cases, natural forms provide inspiration for design, but in others the functions of nature are incorporated into human inspired urban forms to fit within the context of a design project.

LEED SUSTAINABLE SITES

The US Green Building Council LEED system recognizes the importance of green strategies for stormwater management in their sustainable sites criteria. A prerequisite in this category focuses on the prevention of erosion and sediment control. In addition, one credit point is awarded stormwater management strategies or techniques that positively affect rate and quantity of stormwater. One credit point is also awarded for strategies and techniques that focus on treatment of stormwater. In the water efficiency category, in addition to a credit point awarded for reducing landscape irrigation requirements by 50%, using no potable water or no irrigation awards a credit point. An obvious method to avoid use of potable water and irrigation is to recycle stormwater to support plants on the site.

TABLE 1. Stormwater management in LEED NDRS.

	Prerequisite	Credit
Smart Location and Linkage		
Proximity to Water and Wastewater Infrastructure	X	
Imperiled Species and Ecological Communities	X	
Wetland and Water Body Conservation	X	
Floodplain Avoidance		X
Steep Slope Protection		X
Site Design for Habitat or Wetland Conservation		X
Restoration of Habitat or Wetlands		X
Conservation Management of Habitat or Wetlands		X
Neighborhood Pattern and Design		
Compact Development	X	
Compact Development		X
Reduced Parking Footprint		X
Green Construction and Technology		
Minimize Site Disturbance Through Site Design		X
Minimize Site Disturbance Through Construction		X
Stormwater Management		X
Wastewater Management		X

In the "Pilot Version of LEED for Neighborhood Development Rating System," (NDRS) the US Green Building Council includes several categories that incorporate green strategies for stormwater management. While this system is not yet fully in practice, it provides a clear indication of the importance of this topic at the neighborhood level. It is at this level and at even broader scales where some of the most important green contributions to stormwater management can take place. The following items relating to stormwater management are included in the pilot version of this checklist.

GREEN ROOFS

Green roofs may not be the first technique for stormwater management that comes to mind, but they are an important tool for reducing stormwater runoff from industrial, commercial, and residential buildings. Green roofs typically include layered drainage systems and vegetation over a waterproof membrane. They use vegetation and specifically designed lightweight soil mixtures to absorb, filter, and detain precipitation. Compared with traditional asphalt or metal roof systems, green roofs are much more effective, absorbing and storing precipitation, facilitating evapotranspiration, and reducing peak flows. Coupled with other stormwater management strategies, they can be effective in helping to eliminate or significantly reduce off-site discharge. Green roofs may also assist in reducing the introduction of pollutants due to the organic processes of soils and utilization by plants. Traditional roofing systems can also contribute pollutants such as lead, zinc pyrene, and chrysene to stormwater runoff (Van Metre and Mahler 2003).

Green roofs are typically characterized as intensive, semi-intensive, and extensive (US EPA 2000b). They are also distinguished from roof gardens, which are normally intended for human use and may or may not provide some of the same benefits of green roofs. Intensive green roofs typically have greater than 15 cm (6 inches) of growing medium and substrate, while extensive green roofs have less. Semi-intensive green roofs are a hybrid where greater that 25 percent of the roof area is of one type and the remainder is in the other. Extensive green roofs provide many of the same benefits and intensive systems but they are lower maintenance and cost and are not suitable for public access. Semi-intensive or hybrid systems usually allow public use on some areas while providing the benefits of green roofs over a larger rooftop area.

FIGURE 2. Green roofs in Kuppersbusch ecological housing in Gelsenkirchen, Germany.

FIGURE 3. High level aqueducts used to collect and transport excess runoff from green roof system, Kuppersbusch, Gelsenkirchen, Germany.

FIGURE 4. Central green water retention and infiltration zone, Kuppersbusch, Gelsenkirchen, Germany.

Additional benefits offered by green roofs include reducing urban heat island effects, improved energy efficiency by providing greater thermal insulation, better noise buffering, and greater roof durability and life span. Figure 2 shows green roofs at the Kuppersbusch ecological housing project in Gelsenkirchen, Germany (Jones 1998). Rainwater that is not held in the soil and utilized by the rooftop plants is collected through high level aqueducts (Figure 3) and carried to the central retention area (Figure 4) where it is allowed to percolate.

Green roofs are most easily and affordably installed with initial construction of a building. However, stormwater retrofit is possible with some buildings after they are constructed. Many flat-roofed buildings can be adapted for the additional weight of green roofs without significant structural modification. While the cost and complexity of retrofitting buildings for green roofs is greater, increasing market demand and technological advances are bringing costs down. There are a number of companies that now specialize in green roof design, systems, and installation in the US and especially in Europe.

GREEN STREETS AND PARKING

Traditional streets and parking lots contribute to the volume and pollution of stormwater that eventually finds its way into watercourses. Reconsidering traditional approaches to street and parking lot design to reduce and transform paved surfaces to limit and better manage stormwater runoff holds great potential as a green site design strategy. Several approaches are now being undertaken more regularly in an effort to manage stormwater impacts.

Narrower streets, eliminating curb and gutter, and green parking are strategies that have significant environmental benefits, while in many cases reducing costs. The obvious benefits of narrow streets, by reducing the amount of impervious cover, will limit stormwater runoff. In addition, less paving means less area to contribute to the urban heat island effect. Neighborhoods may hold greater aesthetic appeal, and perhaps bringing houses closer together may facilitate greater interaction and sense of community. Eliminating curb and gutter and introducing grass or vegetated swales to carry runoff allows stormwater to be dispersed directly to swales for infiltration rather than collecting along the street with no possibility for removing pollutants. Green parking refers to a range of potential alternatives to traditional impervious parking lots. The principle objectives of green parking are to reduce impervious surfaces and provide opportunities for collection and filtration locally, rather than collecting stormwater and sending it to an offsite system. Alternative materials for green streets and parking are discussed in more detail later in this article.

Many communities in the US now require residential street widths of 32, 36, and sometimes 40 feet. The standard street width is intended to provide on-street parking lanes on each side of the road and two traffic lanes. In many residential neighborhoods, this is in addition to residential driveways and garages for two or three vehicles per unit. Streets may cover up to 40–50% with impervious surfaces in some communities. Traffic volumes in these areas are also usually very low. In addition to generating excess amounts of polluted stormwater runoff, this condition also tends to encourage traffic speeds beyond safe levels in residential areas.

Narrower streets can be used in most residential development that generate less than 500 average daily trips (ADT), perhaps widths of 22–26 feet. Narrower streets could also be feasible for streets with 500–1,000 ADT (US EPA 2007). In some residential communities in Europe (i.e., the Dutch Woonerf), street widths are often narrower with occasional pullouts to pause for oncoming traffic. While attitudes and standards are changing, the most significant impediment to narrower streets is the inflexibility of local road and zoning standards. US communities such as Portland, Oregon and Boulder, Colorado are examples of communities that have modified standards to allow the flexibility to accommodate narrower streets. There are many other examples where developers have created neighborhoods with narrower private streets within innovative projects. Figure 5 illustrates a private, narrow residential street in the False Creek area of Vancouver, Canada.

Eliminating curbs and gutters on streets will typically require installation of a grass or vegetated swale to accept the stormwater runoff from the street. Traditional curbs and gutters are very effective at quickly collecting and delivering stormwater runoff to a central location for storage and possibly treatment. As a result, they provide no opportunity for removal of pollutants. In fact, curbs act as traps where pollutants are held until the next storm carries them away. Elimination of curbs and gutters and the introduction of grassed swales to collect and convey runoff are suitable for a range of conditions. Where adequate space exists and traffic conditions will allow, this approach will allow for filtering, percolation, and reduction of peak runoff volumes and flow velocity. A grassed or vegetated swale is a shallow channel with grass or vegetation along the sides and bottom that is designed to trap pollutants, facilitate infiltration, and reduce flow velocity of stormwater runoff (US EPA 1999c). They are best suited for areas with relatively low flow limited density. Figure 6 shows a grass swale alongside a narrow street in the Oikos residential development in Enschede, Netherlands. Schueler (1997) estimates pollutant removal rates for grassed swales in Table 2.

FIGURE 5. Narrow residential street False Creek, Vancouver, Canada.

FIGURE 6. Grass swale in Oikos residential development, Enchede, Netherlands.

Green parking can respond to a variety of environmental concerns in urban areas. With many parking lots covering large areas and paved with asphalt or concrete, they are prime contributors to the urban heat island effect. They are often planted sparsely and are often clearly visible from adjacent streets, leaving undesirable aesthetic impressions. Many parking lots sit largely vacant most of the time and fill only during major events or at peak shopping periods. From a stormwater perspective, they generate large amounts of stormwater runoff and hold significant quantities of pollutants (Schueler 1994) that are washed into rivers and streams during storms.

Green strategies for parking area design can take several different forms. One of the main strategies is to limit the area dedicated to parking. Municipalities can play an important role by encouraging the construction of parking structures by providing incentives, thereby limiting area occupied by parking. Shared parking and reduced parking ratios can also be encouraged by municipalities by relaxing or modifying standards. Most municipalities set parking ratios according to building floor area and land use type and don't take into consideration adjacent land uses opportunities. The creation of new parking lots can also be discouraged. Some municipalities are also encouraging the use of smaller parking spaces. Parking lots

TABLE 2. Estimated Removal Rates for Grassed Channels (Schueler 1997).

Total suspended solids	81%
Total phosphorous	29%
Nitrate Nitrogen	38%
Metals	14–55%
Bacteria	–50%

needing greater capacity for events or other heavy use periods can be separated into zones corresponding to intensity and duration of use and be designed to respond to the level of use. Limited use areas may be considered for alternative functions at times when not needed for parking.

The same objectives, as with street design, apply to design of parking lots for stormwater management. Reducing stormwater runoff and integrating opportunities for treatment on-site are central to green parking design. Therefore, strategies such as use of porous/permeable paving and other alternative paving systems as well as integrating bioretention and biofiltration can be employed. These topics are explored in more detail later in this article.

POROUS/PERMEABLE PAVING

One of the principle contributors to increase in urban stormwater runoff is extensive areas of asphalt or concrete paving typically used in streets, parking lots, driveways, and sidewalks. Alternatives to these traditional materials exist and offer significant environmental benefits. As noted in the previous section "Green Streets and Parking," limiting paved surfaces is an important first step to reducing stormwater runoff. However, making the remaining paved areas more porous can also make a substantial difference. Porous paving is permeable pavement that will provide some of the same structural characteristics to traditional paving materials but allow stormwater to infiltrate directly into a treatment zone or reservoir. It may substitute for traditional paving in light traffic areas, parking lots, and other areas provided subsoils have adequate permeability rates (1.3 cm or 0.5 inches/hr) and groundwater conditions (1.2 m or 4 feet from bottom of system) are suitable (US EPA 1999).

Porous pavement is often constructed over a stone or gravel reservoir that allows for temporary storage and some filtering before it continues draining into the subsoil. A filter fabric placed beneath the gravel and stone layers screens out fine soil particles. There are various types of porous paving surfaces, including pervious concrete, porous asphalt, permeable pavers, and grass pavement systems. All provide varying levels of structural support while allowing rain and snowmelt to pass through it. Studies in Rockville, Maryland and Prince William, Virginia indicate removal of 82–95% sediment, 65% of total phosphorous, and 82–85% of total nitrogen (US EPA 1999b).

On the surface, pervious concrete and porous asphalt appear to be about the same as the traditional pavements. The difference with porous pavements is that fine materials are eliminated leaving voids that allow water to pass through. Pervious concrete is made from specially formulated Portland cement, coarse aggregate, and water. Sufficient void space allows percolation of water through the pavement. Porous asphalt is similar in that it is comprised of coarse aggregate, bonded with asphalt cement. It also has sufficient voids to allow water to percolate through. These systems can provide increasing amounts of storage by expanding the size of the stone reservoir or perforated pipes can be added in the upper layer of the reservoir to carry off excess runoff after the reservoir is full.

Advantages of porous pavement include pollutant removal from stormwater runoff, reduced runoff volumes, less need for curb and gutter, better skid resistance, and groundwater recharge. There are also disadvantages. Because of the potential for rapid percolation, toxic materials from vehicles (fuel, oil, and other chemicals) may leach through. Porous pavement is not designed to treat these contaminants and could potentially pass them through to groundwater supplies. Many engineers and contractors have little experience with these systems and there is some risk of failure or clogging due to improper installation or maintenance. Anaerobic conditions may develop in soils if they are not allowed to dry out periodically, impeding decomposition. Since this is a new system, there are still outstanding questions concerning their long-term viability. In particular, questions remain over the long-term porosity once resurfaced, the cost of maintenance, and the potential for restoration of porosity in systems that become less effective. They also will likely have a shorter life span than traditional paving systems.

ALTERNATIVE PAVING SYSTEMS

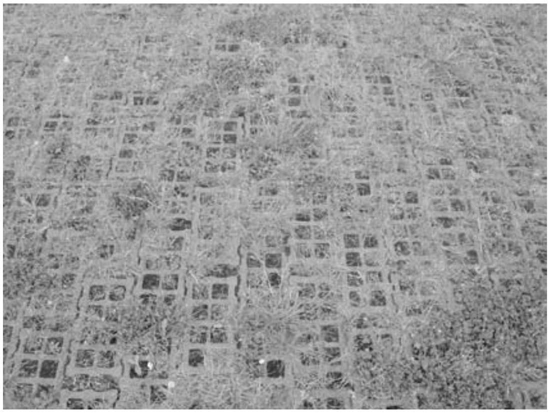
Alternative paving systems are another form of permeable paving that can be used in place of traditional asphalt and concrete paving. They may include paving blocks (concrete or plastic grids), cobbles, gravel, or mulch. There are also several invisible structural support systems for grass paving in areas where traffic is limited. These systems are best used in driveways, parking lots, and sidewalks, although cobbles have been used extensively in Europe for many streets. Depending on the system used, the environmental benefits vary but all have potential to increase percolation of stormwater and reduce volume and velocity of runoff.

Paving blocks are specially formulated concrete or plastic grids or some other combination of voids and structural elements. Voids are filled with soil and allow for infiltration and in some circumstances the planting of grass or other low groundcovers. The subgrade is best prepared like a typical road bed to avoid settling and allow infiltration. When planted with grass, in addition to stormwater benefits, these systems can contribute to reduction in urban heat island effect, improve aesthetic appeal, and provide for multiple use surfaces. Figures 7 and 8 show paving blocks with grass in the parking lot of a Business Park in Castrop-Rauxel, Germay. In hot, dry climates, however, concrete blocks tend to be unsuitable for planting grass or other vegetation due to heat storage in the block that increases soil temperature in the confined voids. In addition, high levels of traffic also create problems in sustaining healthy grass growth. Also, less aesthetically appealing and less effective for reducing urban heat island effect, grass can be replaced with crushed stone to retain the stormwater benefits.

Cobbles, gravel, and mulch all provide superior environmental benefits over traditional concrete or asphalt paving. While cobbles are less effective than gravel or mulch in allowing infiltration of stormwater, the gaps between stones and the increased roughness of the surface provide greater infiltration potential and will reduce the stormwater velocity to some degree. Gravel and mulch are both pervious materials and although they are not suitable for many applications can be considered for low use or temporary use areas. With each of these systems, settling can become a problem and sometimes regrading or adding new material is required to preserve a fit surface.

FIGURE 7. Paving blocks planted with grass in Business Park, Castrol-Rauxel, Germany.

FIGURE 8. Detailed view of paving blocks in Business Park, Castrol-Rauxel, Germany.



Invisible structural support systems for grass paving are now used more frequently, typically in occasional use situations and provide an aesthetically pleasing, permeable surface. Emergency lanes, service access, temporary or overflow parking, residential driveways, and other light use areas are most appropriate for this application. This system provides a continuous grass surface with a structural support system below the surface. Figure 9 shows a service lane at the Sydney, Australia Olympic Park constructed with invisible grass paving.

The subgrade is prepared in the same fashion as road beds and a specially designed and fabricated

FIGURE 9. Service lane constructed with invisible grass paving Olympic Park, Sydney, Australia.

plastic mat or layer, often provided in rolls, is placed over the prepared base. The plastic mat is 5–8 cm (2–3 inches) thick with connected cell voids that are filled with soil and planting medium. Sod or grass seed is then placed on the surface layer to create a uniform grass surface. This system has about the same permeability as a normal grass lawn and, depending on slope conditions, would retain moisture to allow for better infiltration to subsoil and potentially to groundwater table. The most common problems with this system are related to improper installation and overuse. Because of lack of familiarity, these systems are sometimes installed without a properly prepared base and would then be subject to settling in areas of more frequent use or heavier vehicles. Overuse will result in inadequate regeneration of the grass surface. While the grass surface does become damaged as a result of use, normal use patterns are infrequent and the grass will regenerate naturally. This type of system will also require similar maintenance regimes as a traditional grass lawn, such as mowing, fertilization, and possibly irrigation.

BIORETENTION AND BIOFILTRATION

Bioretention and biofiltration use soils and vegetation to remove pollutants from stormwater runoff, often conveyed as sheet flow to a treatment area. Runoff is filtered and may percolate through to the water table or evapotranspire. Runoff can also be stored and be released over a longer period of time. This technique is often used to store and treat stormwater that has run over impervious surfaces, collecting contaminents. It is a useful strategy for median strips, parking lot islands, and swales. Benefits include enhanced water quality in downstream areas and moderated peaks in stormwater discharge. Ancillary benefits include shade, windbreaks, noise absorption, wildlife habitat, and aesthetic value. Figures 10 and 11 show bioretention and biofiltration median strips in residential streets in Victoria Park, Sydney, Australia. The street is designed with an inverted crown so that water drains to the median strip and is retained and treated.

There are a range of configurations employed, but ideally, the treatment area may consist of a grass buffer strip, a sand edge and base, a ponding area planted with vegetation, and a mulch surface that is depressed

FIGURE 10. Residential street with bioretention and biofiltration median strip in Victoria Park residential development, Sydney, Australia.

FIGURE 11. Bioretention and biofiltration median strip in Victoria Park residential development, Sydney, Australia.

TABLE 3. Estimated bioretention and biofiltration removal rates (Davis et al. 1998 and PGDER 1993).

Pollutants	Removal Rates
Total Phosporous	70–83%
Metals (Co, Zn, Pb)	93–98%
TKN	68–80%
Total Suspended Solids	90%
Organics	90%
Bacteria	90%

by about 15 cm (6 inches). The various bioretention components are designed to perform specific functions. The grass buffer strip filters particulates and reduces runoff velocity. The sand edge and base distribute flow throughout the bioretention area and also provide aeration and drainage for the planting soil above (about .5 m or 18 inches). Temporary storage is provided in the ponding area while the runoff percolates into the soil and evaporates (US EPA 1999a, 2000a). Particulates not filtered out by the grass filter strip and sand settle in the ponding area. Vegetation litter or surface mulch also filters pollutants and provides for the growth of organisms that will degrade petroleum-based pollutants and other materials. This layer as well as the vegetation cover will help reduce erosion. Clay soils in the planting mix help with absorption of nutrients, heavy metals, hydrocarbons, and other pollutants. Plants roots also take up moisture captured in soil voids. The size of bioretention areas is a function of the drainage area and runoff generated. Davis et al. (1998 and PGDER 1993) have documented that bioretention and biofiltration can potentially remove pollutants at the following rates.

This technique may not be appropriate where the water table is high (within 1.9 m or about 6 feet of the ground surface) because adequate filtering and removal of pollutants may not be possible before water reaches the water table and ground water supplies may become contaminated. Also, in cold climates where soil may freeze, infiltration into the lower soil horizons may be prevented. Clogging is sometimes a problem if high sediment loads are present in runoff, so steep slopes and unstable soils should be avoided.

CONSTRUCTED STORMWATER WETLANDS

Stormwater wetlands are an effective way of treating contaminated stormwater. These constructed systems are designed so that as stormwater flows through the wetland, settling and biological uptake removes pollutants from the water. These systems also improved aesthetic value and provided new wildlife habitat. Natural wetlands are sometimes used to treat stormwater and are actually effective in doing so when runoff has been pretreated; it is not recommended that these areas be used in this way. The introduction of additional volume of contaminated water alters the hydrology and can cause damage to these areas.

Stormwater wetlands are best designed for the specific purpose of treating stormwater and will have different composition and functions than a natural wetland. Constructed wetlands will typically have less biodiversity of plant and animal life and will also have different amounts of shallow and deep water and dry storage area. In addition to pollutant removal, these systems can also be used to assist with flood control, ground water recharge, and channel protection. Figure 12 illustrates how a constructed wetland in Waitangi Park in Wellington, New Zealand is used as an educational and aesthetic feature as a central element in a major urban waterfront park. It takes water from an urban stream with contaminated stormwater and treats using a series of ponds and vegetation. Figure 13 shows a constructed wetland that stores stormwater runoff from a residential development at Oikos in Enschede, Netherlands.

US EPA (2007b) describes five design variations in wetland design, shallow marsh, extended wetland detention, pond wetland system, pocket wetland, and

FIGURE 12. Constructed wetlands as an educational and aesthetic feature in Waitangi Park, Wellington, New Zealand.

FIGURE 13. Constructed wetland as a central feature in Oikos residential development in Enschede, Netherlands.

gravel-based wetlands. In each case it is important to incorporate pretreatment to settle out coarse sediment particles. This will reduce maintenance on the larger permanent wetlands pool. Normally, this is done with a settlement forebay, a small pool about 10 percent the size of the main wetlands. The shallow marsh design holds most of the water volume in relatively shallow high marsh or low marsh depths. The forebay is deeper at the inlet to the wetland and at a small pool at the outlet. Typically, more land is required for this system. The extended detention wetland is similar to the shallow marsh with additional storage area above the marsh. This is intended to detain greater volumes of water for 12 to 24 hours. The pond/wetland system combines a deeper wet pond (2–2.5 m or 6–8 feet) with a shallow marsh. The pocket wetland intersects with the groundwater helping to maintain a permanent pool. This option might be suitable with limited amounts of drainage into the pool. Gravel-based wetlands allow runoff to flow through rock filters with wetland plants at the surface. Pollutants are taken up by the plants and also removed through biological activity with the rocks. This system is fundamentally different since it does not act like a wet pond, instead it is more similar to a filtering system.

CONCLUSIONS

Urbanization and inadequate responses to urban stormwater have contributed to the problem of water quality, flooding, and altered river and stream dynamics. As society continues to urbanize, it is important to develop stormwater management systems that do not contribute to larger environmental problems. Green site design strategies that focus on environmentally friendly stormwater management have the potential to alter the current direction of increasing impervious surfaces. In addition, as existing systems antiquate, opportunities to retrofit to mimic the functions of nature and create green infrastructure exist. Many of these strategies are immediately cost effective and can be implemented with increased awareness and cooperation of municipalities who oversee and approve new development and redevelopment projects. Some communities have chosen to incorporate green infrastructure practices already and more are changing standards and processes to accommodate new ideas. Innovative green approaches to stormwater management are an important part of this transformation.

REFERENCES

Davis, A., M. Shokouhian, H. Sharma, and C. Minani. 1998. "Optimization of bioretention design for water quality and hydrologic characteristics." Report 01-04-31032, Final report to Prince George's County, Maryland.

Dunn, A. D. and N. Stoner. 2007. "Green light for green infrastructure." *The Environmental Forum.* May-June.

Jones, P. 1998. "Experimental community – architectural design and social housing project in Gelsenkirchen, Germany." *Architectural Review.* April 1998.

Kloss, C. and C. Calrusse. 2006. "Rooftops to Rivers: Green strategies for controlling stormwater and combined sewer overflows." Natural Resources Defense Council.

Prince George's County Department of Environmental Resources (PGDER). 1993. Design manual for bioretention in stormwater management. Division of Environmental Management, Watershed Protection Branch, Landover, MD.

Schueler, T. 1994. "Sources of urban storm water pollutants defined in Wisconsin." Watershed Protection Techniques, 1(1):30-32.

Schueler, T. 1997. "Comparative pollutant removal capacity of urban BMP's: A reanalysis." Watershed Protection Techniques, 2(2):379-383.

U.S. Environmental Protection Agency. 2003. "Protecting water quality from urban runoff." Nonpoint Source Control Branch, EPA 841-F-03-003.

US Environmental Protection Agency. 1999a. Stormwater technology fact sheet: Bioretention. Office of Water. EPA 832-F-99-012, September 1999.

US Environmental Protection Agency. 1999b. Stormwater technology fact sheet: Porous pavement. Office of Water. EPA 832-F-99-023, September 1999.

US Environmental Protection Agency. 1999c. Stormwater technology fact sheet: Vegetated Swales. Office of Water. EPA 832-F-99-006, September 1999.

US Environmental Protection Agency. 2000a. Bioretention applications. Office of Water. EPA-841-B-00-005A, October 2000.
US Environmental Protection Agency. 2000b. Vegetated roof cover. Office of Water. EPA-841-B-00-005D, October 2000.
US EPA. 2007. National pollutant discharge elimination system (NPDES). http//www.epa.gov/gci-bin. Accessed September 14, 2007.
Van Metre, P. and B. Mahler. 2003. "The contribution of particles washed from rooftops to contamination loading to urban streams." *Chemosphere.* 52: 1727-1741.