IMPLEMENTATION OF BIORETENTION SYSTEMS: A WISCONSIN CASE STUDY[1]

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ABSTRACT: The implementation of various bioretention systems was analyzed, including rain gardens, vegetated swales, trenches, and infiltration basins in the St. Francis subdivision, Cross Plains, Wisconsin. Through the examination of archival data and interviews with key participants, it was found that although regulatory and political pressures encouraged the inclusion of bioretention, current standards for storm water management prevailed. The developers had to meet both existing requirements and anticipated rules requiring infiltration. As a result, bioretention systems simply supplemented, rather than replaced, traditional storm water practices. The confusion surrounding dual standards contributed to substantial delays in the negotiations among relevant stakeholders in the watershed. It is concluded that the St. Francis subdivision serves as both a cautionary tale and a bioretention success story. As a caution, this situation demonstrates the need for careful review and refinement of existing storm water ordinances to incorporate water quality improvement technologies, such as bioretention. The demonstrated success of the St. Francis development, however, is that it became a positive prototype for best management storm water practices elsewhere in the region. In addition, the water quality monitoring data from the site has contributed to development of a new county ordinance, the first in Wisconsin to address both quantity and quality of storm water runoff.
(KEY TERMS: storm water management; best management practices; infiltration and soil moisture; rain gardens.)

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INTRODUCTION

Traditional storm water systems are designed to concentrate and convey runoff away from source areas. Runoff is stored in detention basins to reduce the peak flow and control the rate of discharge, and the total volume is then routed out of the watershed via streams. These practices are very successful in eliminating frequent flooding and reducing the localized and short term impacts of environmental pollution (Butler and Parkinson, 1997; Huhn and Stecker, 1997). However, because runoff carries sediment, nutrients, and synthetic chemicals that accumulate in the aquatic environment, the diversion of storm water also reduces ground water recharge and baseflow (Correll, 1997; Huhn and Stecker, 1997).

Direct infiltration of storm water, by contrast, can reduce peak flow and total volume, thereby ameliorating stream bank erosion and increasing ground water recharge and baseflow (Fujita, 1997; Bucheli *et al.,* 1998). As runoff infiltrates, depending on site conditions, suspended solids, phosphorus, metals, some pesticides, and organic compounds are adsorbed and water quality improves, although highly water soluble compounds, such as nitrates and salts are not removed and can contaminate ground water (Appleyard, 1993; Pitt *et al.,* 1996; Bucheli *et al.,* 1998; Lloyd *et al.,* 2002).

Bioretention systems are one option for direct storm water infiltration. These systems consist of a depression over porous soil, covered with mulch, and

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planted with a variety of vegetation. Runoff from an impervious area is directed into the bioretention area, where it infiltrates or is lost through evapotranspiration. The plants maintain soil porosity, encourage biological activity, and take up pollutants (Davis *et al.,* 2001; U.S. Environmental Protection Agency, 2001; Prince George's County Department of Environmental Resources, 2002). Bioretention includes window boxes that capture rainfall, small vegetated depressions adjacent to downspouts (rain gardens), vegetated swales (bioretention islands), and infiltration basins. These systems operate in the same general way but differ in size.

Bioretention was originally designed to minimize surface water runoff volume, but increasingly it is being used to improve ground water quality. Bioretention is recommended as a structural Best Management Practice used to meet the requirements of the national storm water program under Section 402(p) of the Clean Water Act (U.S. Environmental Protection Agency, 1999). In particular, rain gardens have attracted attention (Table 1) because they are aesthetically pleasing, simple to build, and can be very effective when infiltration is focused to maximize recharge (Kercher, 2003; Dussaillant *et al.,* 2004). A rain garden is a landscaped garden in a small shallow depression that receives the runoff from one household or lot through layers of mulch and porous soil (Dussaillant, 2002; Prince George's County Department of Environmental Resources, 2002).

Although many sites around the country have incorporated rain gardens and other bioretention systems (Table 1), uncertainty about the implementation and regulatory processes still exists. The process of implementation of bioretention practices in the St. Francis subdivision in Cross Plains, Wisconsin, was analyzed. The subdivision was one of the first residential developments in Wisconsin to include bioretention systems in its site design. A case study approach was used because of little prior knowledge of relevant variables and relationships. Two questions were addressed: (1) which technical, social, and regulatory processes hindered or assisted the implementation process of storm water bioretention practices in the St. Francis subdivision; and (2) in the future, how can this process be improved?

METHODS

The research proceeded through three phases. Initially, background information on stormwater infiltration and bioretention was gathered and a pilot study on homeowner attitudes and knowledge of rain gardens conducted in the Madison area in 2001 (M. Hornung, R. Veltman, and H. Morzaria-Luna, unpublished data) was analyzed. A series of interviews conducted by the Wisconsin Department of Natural Resources (WDNR) about barriers to adoption of bioretention systems were analyzed. Physical and engineering data on the St. Francis subdivision were then collected, including reviews of topographic and soil maps, street and utility construction plans, as well as historical documentation.

In the second phase, in 2002, a series of open ended interviews was conducted with key participants involved in the development of the St. Francis subdivision. The public works engineer for the Village of Cross Plains, two project design engineers who developed the plans for the subdivision, the developer of the project, a representative from the Dane County Regional Planning Commission (RPC), and a staff person from the Land Conservation Department who was involved in monitoring the site were interviewed. The questions were similar for all the interviews, but modified accordingly to the area of expertise of the interviewee. The interviewees were asked to describe how the bioretention component emerged and developed and to identify the primary source(s) of resistance. Follow-up phone interviews also were conducted with third parties referred by the initial interviewees.

Finally, in the third phase of the study a list of factors described as assisting and/or hindering the implementation process was developed. Feedback for the analysis was sought from two engineers unconnected to the project, but with extensive experience working with watershed development issues (one from Montgomery Associates: Resource Solutions in Madison, Wisconsin, and another from Peer Engineering in Bloomington, Minnesota).

Study Site

The St. Francis subdivision (Figure 1) is located 19 km west of the City of Madison, Wisconsin, in the Village of Cross Plains (population approximately 3,000). Before development, the property was farmland. The plat is composed of 20.9 buildable hectares and 8.7 environmental corridor hectares. When completed it will have 102 residential units (Table 2). The subdivision has variable topography with a 2 to 8 percent slope.

Cross Plains is located in the transition zone between the glaciated and unglaciated areas of Dane County. The upland areas contain well drained glacial till and colluvial deposits. In lowland areas, poorly drained soils are subject to flooding and a high water

TABLE 1. Urban Development Projects Where Bioretention Practices Have Been Implemented in the United States.

Location	Implementer	Project	Implementation*	Practice**
Frederick County, Maryland[1]	Ecosite, Inc.	Pembroke Subdivision	N	3,4,5
Seattle, Washington[1]	Seattle Public Utilities and Seattle Transportation Department	Urban Creeks Legacy Program. SEA Streets	R	5,7
Sherwood, Arkansas[1]	Terry Paff, Developer	Gap Creek Subdivision	N	1, 6
Maplewood, Minnesota[1]		Maplewood Water Gardens	R	5
St. Paul, Minnesota[1]	Upper Swede Hollow Neighborhood Association	Maria Bates Rain Garden	R	4
Mount Rainier, Maryland[2]	Prince George's County Department of Environmental Resources	HIP Artist's House	R	1
Port Towns, Maryland[2]	Port Towns, Prince George's County and Maryland State Highway Administration	Bladensburg Streetscape Project	R	4
Austin, Texas[3]		Alta Vista Planned Unit Development	N, M	5
Somerset, Maryland[4]	Prince George's County Department of Environmental Resources	Somerset Subdivision	N	4
Carrboro, North Carolina[5]	Giles Blunden, Architect	Pacifica Cohousing	N	1
Minneapolis, Minnesota[6]	Friends of Bassett Creek	Bassett Creek	R	4
St. Paul, Minnesota[6]	Friends of Swede Hollow	Lower Phalen Creek	R	4
Grayslake, Illinois[7]	Applied Ecological Services, Inc.	Prairie Crossing		5,6
Lake Wisconsin, Wisconsin[8]	Heffron and Associates	The Water's Edge	N	4
Seattle, Washington[9]	City of Seattle	Green Street Project	R	1,2,5

*Implementation: R = retrofit; N = new construction; and M = monitoring for pollutant removal.

**Includes housing and living areas. Does not include parking lots or highways. Practices: 1 = bioretention (unspecified); 2 = window boxes; 3 = sediment detention basins; 4 = rain gardens; 5 = swales; 6 = wetlands and natural area preservation; and 7 = retention grading of lawns.

[1]Lehner *et al.,* 1999.

[2]Prince George's County, 2001.

[3]ASCE, 2001.

[4]Coffman, 1995.

[5]Carrboro Collaborative Development Association, 2002.

[6]Friends of Basset Creek, 2004.

[7]Apfelbaum *et al.,* 1994.

[8]Daniel Heffron, Heffron and Associates, personal communication, February 13, 2002.

[9]Wulkan, 2001.

table. Environmental corridors exist on the lower areas and bottomland soils because they are unsuitable for development (Dane County Regional Planning Commission, 2000).

St. Francis is located along a small tributary, Brewery Creek. This creek drains into the Black Earth Creek, a high quality (Class 1) trout stream with sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity (WDNR, 2003). The downstream segments of Brewery Creek have natural meanders and fair habitat quality. Brown and rainbow trout sometimes use these areas as a refuge from predation. Ground water recharge supplies approximately 80 percent of Black Earth Creek's flow volume (Genskow and Born, 1997). Over time, more than $2 million (public and private) have been used to

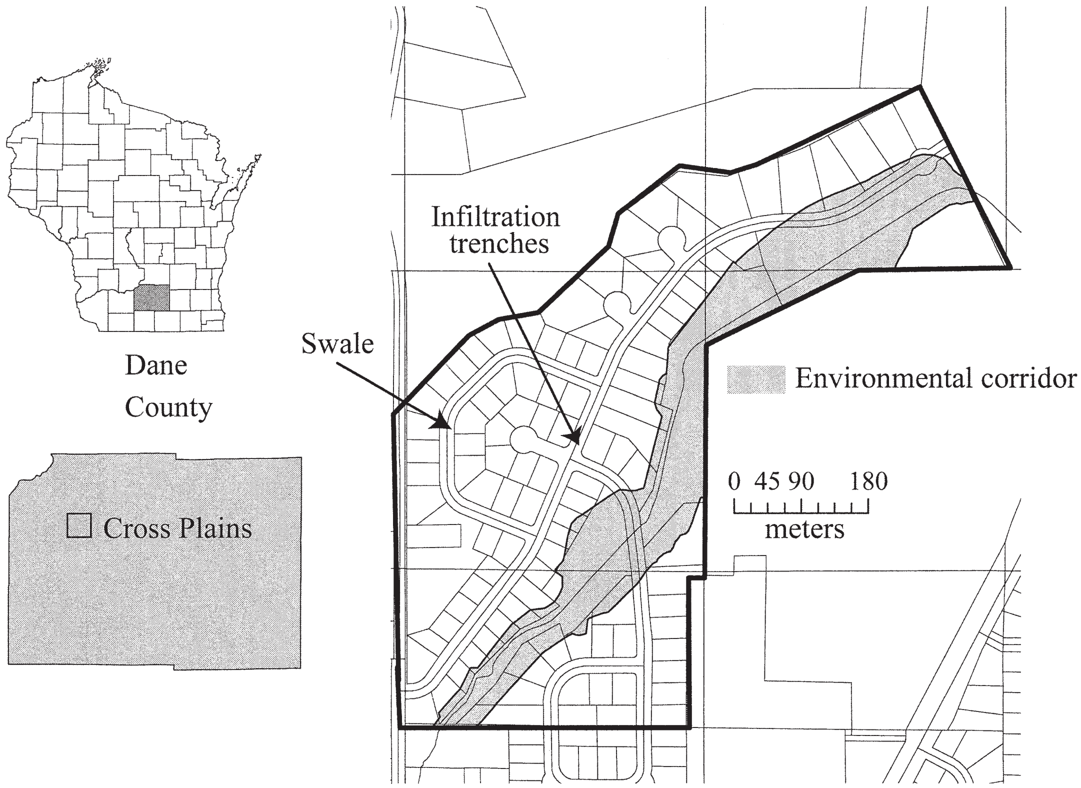

Figure 1. Location and Plan of the St. Francis Subdivision Located in the Village of Cross Plains, Wisconsin, Showing Some of the Locations of Bioretention Practices Used in the Design of the Subdivision.

TABLE 2. Land Use Characteristics of the St. Francis Subdivision, Cross Plains, Wisconsin.

	Number of Housing Units	Hectares	Density (hectares/unit)	No. of People
Single Family	91	16.3	0.18	291
Two Family	20	1.4	0.07	45
Multifamily	4	3.2	0.80	160
Dedicated Right of Way		5.0		
Park and Open Space		3.8		
Farm Buildings		0.9		
Existing Residences	3	0.6	0.20	
Totals	118	31.2		

Note: Information from R. Roth, unpublished engineering design for the St. Francis Plat.

improve trout habitat in the Black Earth Creek watershed (Mayers, 2001). This money includes a state funded watershed program to support cost sharing of best management practices that reduce nonpoint pollution from urban areas, dairy feedlots, and agricultural fields.

Engineering Practices

During the site planning process, hydric soils and permeable areas, where infiltration practices could be located, were mapped. The site analysis was used to prepare a plan that incorporated the following practices: a naturally vegetated buffer along Brewery

Creek, protection of existing wooded areas, deep tilling to increase infiltration and reduce the effects of soil compaction, storm water storage and infiltration swales behind all house sites, and storm water storage and infiltration swales within cul-de-sacs and boulevards (Dane County, 2002a).

The bioretention systems implemented in St. Francis (Figure 1) include rain gardens, vegetated swales, trenches, and infiltration basins. The design goal of the storm water engineering plans is to infiltrate the one-year storm runoff. Water quality improvement is expected as the first flush of runoff is contained, since it carries the majority of pollutants and has higher temperatures. The plan predicts no increase in the rate of storm water drainage from the developed site compared to predevelopment during two-year to 50-year storms. Additionally, it should allow a 100-year storm to pass safely (R. Roth, General Engineering, Portage, Wisconsin, unpublished engineering design for the St. Francis Plat).

A deed restriction requires that each lot in the subdivision have an 18.6 m^2 minimum area rain garden. The Village Building Inspector checks on the deed restriction requirement when approving initial house construction plans and subsequently in response to complaints. A landscape architect is required to design the rain garden and the Architecture Control Committee of the subdivision needs to approve the plan. The objective is that the rain gardens and the swales in 7 to 9 m easements between lots will infiltrate the one-year storm in each lot. Vegetated swales convey larger storm runoff to the street. The swales are shallow channels with small holding areas created by depressions that allow the water to pond and infiltrate (R. Roth, unpublished data).

The streets are designed as boulevards with a sunken median that contains 11 turf lined infiltration trenches. Trenches are 0.5 to 3.0 m deep and backfilled with stone in order to create an underground reservoir. The runoff is temporarily retained in the backfill until it can percolate into the soil beneath or into the perforated drainpipes. Infiltration basins occupy the center of each of the cul-de-sacs. The basins are designed to store a defined volume of runoff, allowing it to exfiltrate through the sides and floor into the underlying permeable soil. Underneath each trench and basin are perforated drainage tiles (15.24 cm) with socks that connect the series of trenches. Low profile curbs on the median cause road runoff to sheet flow into the trenches and basins. The design required variances for narrower street widths (4.9 m boulevard lanes; 8.5 m street widths wherever possible) because of the boulevard strips and lower curbs.

Overflow standpipe structures drain water over depths of plus or minus 45 cm to a storm sewer line, which leads to two larger detention/sedimentation ponds adjacent to Brewery Creek. Each pond has sump structures to facilitate drainage and emergency spillways to accommodate overflow from the ponds to the creek in the event of very large storms (while also reducing thermal impacts).

ANALYSIS

Inclusion of Storm Water Bioretention Systems in the St. Francis Subdivision

Regulatory and political pressures facilitated the inclusion of bioretention practices in the St. Francis subdivision. Foremost, residents of the Black Earth Creek watershed are very concerned about protecting the natural resources in the area and had rejected previous plans to develop the property. New federal requirements resulting from the implementation of the National Pollutant Discharge Elimination System mandate addressing construction site erosion and sediment control (U.S. Environmental Protection Agency, 2001). In addition, at the time St. Francis was being planned, Dane County was reviewing local storm water regulations to address water quality, and the WDNR wanted a test site for rain gardens. Staff at the WDNR and Land Conservation Department introduced the developer to bioretention practices, and he agreed to include them because, as a lifelong resident of the area, he wanted to protect the creek as well. The developer also gained six more lots by using infiltration systems. In addition, a storm water management plan that uses native vegetation and emphasizes environmental issues can make a development more desirable and marketable (Lloyd *et al.,* 2002; Prince George's County Department of Environmental Resources, 2002). As a result, the engineers were encouraged by the developer to use infiltration and bioretention as part of the storm water management plan.

Projects where stakeholders are willing to test novel technology serve as models to promote further change and provide publicity to bioretention (Dane County, 2002b, 2003). St. Francis was very successful in this role. The developer received a Dane County Lakes and Watershed Commission award for his stewardship. Preliminary water quality data collected by the Land Conservation Department indicated little or no impact from the St. Francis development (Dane County, 2003). This information was used in the new Dane County Stormwater Management Ordinance. The new ordinance addresses both quantity and quality of storm water runoff from any development that has 1,858 m^2 or more of impervious surface. The standard is no increase in the rate of runoff for a site after development compared to predevelopment, in the event of a two-year and a ten-year storm. The ordinance indicates downspouts, driveways, and other impervious areas must be directed to pervious areas where feasible; and rain gardens, infiltration trenches, and porous pavement are included recommended practices in the accompanying manual (Dane County, 2002a).

Implementation Process

The developer of the St. Francis subdivision initially proposed a smaller development on the south side of the Brewery Creek, but the Village of Cross Plains requested a plan for the whole property so they could approve the development of the property in one step. This requirement substantially increased the area of the plat and led to greater regulatory and political scrutiny of possible storm water impacts to Brewery Creek.

In Wisconsin, subdivision plats and associated storm water management plans are approved by municipalities. The Village of Cross Plains's storm water ordinance requires control of post- development storm water flows to predevelopment levels for two-year storm events. In addition to village storm water requirements, the WDNR requires a NR216 storm water permit for land disturbances greater than 2 hectares that discharge into state waters. This permit aims to eliminate to the "maximum extent practicable" pollutants in municipal storm water runoff (WDNR, 2002). The St. Francis subdivision also required approval to extend the village urban sewer service area from the RPC. This agency conducts water quality planning for the region and delineates areas for urban development and places where environmental resources should be protected. The location of the site next to the Black Earth Creek also brought the issue to the attention of local environmental groups such as Trout Unlimited.

The Village of Cross Plains and the engineers compromised on allowing a deviation from the water quantity requirement, in exchange for bioretention systems that would improve water quality by capturing sediment and lowering runoff temperature. Although bioretention is not common in the area, the engineers used examples from other regions, including Minnesota, Illinois, and Maryland (Table 1). The engineers received help from the Land Conservation Department with the design of the infiltration practices in exchange for allowing the Department to install monitoring stations above and below the site. From 2001 to 2003, sedimentation, temperature, discharge, and other water quality parameters were assessed. The RPC questioned whether infiltration systems could be trusted to provide long term storm water quantity protection. Rain gardens were a problem because they were planned in private yards, and the urban sewer service extension requires a publicly managed storm water system. Neither the developer nor the Village wanted the responsibility of rain garden maintenance. In other subdivisions, like The Water's Edge (Table 1), rain gardens have been built in the public right of way to avoid this issue. The RPC decided to exclude the effects of the rain gardens from the storm water management plan and required further site design changes such as adding a wider stream buffer and detention ponds. Rain gardens remained as part of the deed restriction for each lot.

Overall, the approval process required three years from the initial proposal until construction (R. Roth, personal communication, March 27, 2002).

Obstacles and Opportunities in the Implementation of Bioretention

One major social obstacle to the implementation of bioretention was revealed during the negotiation process among relevant stakeholders in the watershed. The developer and government agency representatives from Land Conservation Department, WDNR, and the RPC all indicated that their own role and responsibilities had been misunderstood by the other participants in the negotiations and by the public, as well. For example, staff from RPC noted that a commonly held view of their agency is that they err on the side of conservation and of course would sign off on any plan that encouraged infiltration techniques. RPC staff emphasized that this misrepresents their mandate. Although they encourage low impact solutions, part of their job is to consider how deed restrictions and rain garden maintenance could be enforced. Staff noted that because of their close scrutiny of how enforcement was possible, some interpreted their hesitation as a lack of support for the project as a whole. The developer noted that he was surprised and somewhat unprepared for the level of resistance from the RPC and for the number of meetings he would ultimately have to attend before the project was approved. When the RPC board delayed approval of the St. Francis project, the developer reasoned that some of the board members thought he was using the modified storm water management design for economic gain, "pure and simple," and therefore it really did not merit a high priority on the board's agenda.

Over time, as relationships developed, the misunderstandings over stakeholder roles and expectations dissipated, replaced to some extent by mutual trust and respect. The developer said that as things proceeded he was very encouraged by the help and involvement of agency officials. Staff members from the WDNR and Land Conservation Department were impressed by the efforts from the developer to ensure that the project was approved and completed adequately. One WDNR staff person noted that he was impressed by the fact that the developer often made spot visits to the site to be sure the contractors were maintaining the silt fences and complying with other specifications of the project, "He didn't have to do that, you know." Therefore, although stereotypes were a formidable obstacle in the beginning, through the process of sharing knowledge, networks developed between various agencies and private interests that will likely aid the inclusion of bioretention techniques in the future.

The physical design requirements in the St. Francis subdivision were the easiest part of the process. As the site engineers described it, "the impermeable surface area could be calculated; the quantitative measures of peak flow and volume could be determined; flow patterns could be established; and the appropriate structures could be designed." Likewise, the developer and the engineers systematically addressed and solved various technological and economic obstacles in the early stages of the project, such as calculating the minimum size of a rain garden to infiltrate a one-year storm. Both the developer and the engineers concluded that they gained experience they could use in the future, should they choose to use bioretention techniques again.

Ordinance and governance structure proved to be the most intractable obstacle during the implementation of bioretention techniques at the St. Francis site. With the exception of the RPC, the stakeholders thought that including bioretention technology would lessen the perceived impacts of development and ensure rapid approval of the St. Francis subdivision. In fact, having to consider both existing ordinances and the anticipated future requirements turned out to be much more challenging than grappling with either aspect would have been alone. Engineers had to show that the bioretention practices would not interfere with traditional storm water management practices. In accordance with traditional storm water plans, detention basins, sewers, curb, and gutters were built in St. Francis. The bioretention requirements were simply added on top of existing requirements. A WDNR staff person described the final design as "like so many barnacles on a ship." That is, more regulatory weight was added to the existing ship of storm water ordinances, but elimination of redundant or reconciliation of contradictory requirements did not occur.

By way of perspective drawn from other situations, in a subdivision in Australia, where bioretention was part of the storm water design, the developer also had to build a conventional drainage system, but the success of the storm water infiltration management plan resulted in similar infiltration practices being approved elsewhere without such conditions being placed on the design teams (Lloyd *et al.,* 2002). In Prince George's County, Maryland, the only region in the United States where bioretention practices are now in common use (Table 1), the alternative technologies were initially adopted and encouraged by the local governance, as a response to the increasing pollution in the Chesapeake Bay. In this case, collaboration between the academic community, local government, and local developers was key to the acceptance of bioretention practices (U.S. Environmental Protection Agency, 2001; Prince George's County Department of Environmental Resources, 2002). In other areas where bioretention has been implemented (Table 1), the initiative has come from local grass roots groups, environmental agencies, or developers.

Rain Gardens Remain Part of St. Francis as Deed Restrictions

Rain gardens, the most innovative part of the storm water management design, were not included in the final version of the plan. Because the deed restrictions made it difficult to enforce maintenance, rain gardens were excluded. Nonetheless, the design engineers, developer, and WDNR staff remained committed to including rain gardens in each lot. Homeowners receive a brochure on rain gardens prepared by the WDNR and references to landscaping companies in the area. They are responsible for hiring a landscaper to design the rain garden and for maintenance. Building inspection at the end of construction will check for compliance with the deed restriction, but no further oversight will occur unless there is a complaint.

Participants' opinions disagreed on whether homeowners will maintain the rain gardens. The developer viewed homeowners as very amenable to innovative storm water management techniques and willing to comply with the deed restrictions. Staff at the RPC argued that homeowners would be unlikely to maintain rain gardens. Personnel at the WDNR believed that the public would probably need to be educated regarding rain gardens. In a pilot study on homeowner knowledge of rain gardens and attitudes towards adoption conducted in the Madison area in 2001, several negative perceptions to the adoption of rain gardens were identified (i.e., rain gardens encourage mosquitoes, require too much work, are expensive to design and plant, and promote weeds) (M. Hornung, R. Veltman, and H. Morzaria-Luna, unpublished data). Liability and possible damage to foundations were also mentioned. This study concluded that a homeowner with average ecological knowledge needed extensive education before he would build and care for a rain garden.

How Can the Implementation of Bioretention Be Improved?

The authors believe that further efforts should be directed to implementing rain gardens as a storm water management practice because they have several advantages over other bioretention practices. Rain gardens are an appealing landscape feature that can be designed to a certain standard, with a known soil profile, vegetation receiving area and topography (Dussaillant, 2002). Also, rain gardens can be included in new designs or retrofitted inexpensively into existing areas (Prince George's County Department of Environmental Resources, 2002). Some suggestions to promote public acceptance and participation include outreach programs, demonstration rain gardens, hands-on design workshops, and credit plans where homeowners who infiltrate their stormwater on-site could receive a reduction on the sewer fee.

However, these findings suggest that any policy aimed at modifying the approach to storm water management must originate within the governance structure. Attention must be concentrated on reviewing and reconfiguring existing storm water regulations and ordinances. Although radical changes will not occur overnight, gradual additions to the standard design are important milestones to the eventual widespread acceptance of bioretention in storm water management plans (Lloyd *et al.,* 2002). The new Dane County Stormwater Management Ordinance is an excellent example of how bioretention can complement the traditional storm water management approach.

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