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National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments

Proceedings
Chicago, IL
February 9-12, 1998

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Technology Transfer and Support Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
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Introduction

Water resource managers have been successful in developing approaches for reducing nonpoint source pollution in newly developing urban areas. Issues become increasingly complex, however, when managers are faced with the challenge of reducing nonpoint source impacts within previously developed urban environments. A diverse assortment of resource management tools, or “retrofits,” is being developed, but their implementation has been hampered by a lack of technology transfer opportunities. The ***National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*** was designed to address these issues and to transfer much-needed information to state and local water resource practitioners.

Held in Chicago, Illinois, on February 9-12, 1998, the conference program brought together an array of progressive scientists and researchers, along with managers of successful local retrofit projects from across the country. Session topics included retrofit opportunity identification, modeling and monitoring approaches for retrofit applications, conservation design strategies, innovative financing approaches, evaluating results and measuring success, newly emerging technologies, urban revitalization issues, riparian reforestation, and public education and involvement programs.

During the conference, a series of speakers presented papers, 43 of which are reproduced in these proceedings. The purpose of this document is to present these papers and provide information to individuals unable to attend. All papers included were peer reviewed. This document will be useful to individuals who are interested in information about retrofitting techniques and approaches to improving protection of urban water resources. A list of the nearly 300 attendees is provided following the papers.

Contents

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

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Securing the Urban Greenfrastructure: Integrating Stormwater Management with Regional Growth Management

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Introduction

As a representative of the Coalition for a Livable Future[1], I was asked to present information on what we are doing in the Portland, Oregon and Vancouver, Washington metropolitan region to integrate the "Urban Greenfrastructure" into our growth management strategies. I will first describe the context in which we are working to integrate more progressive stormwater management and Greenspace (natural area) protection into regional growth management strategies. Then I will discuss the efforts of the Coalition for a Livable Future to further integrate that work into a framework that includes social and environmental growth objectives.

The Portland Park Bureau's 1903 master plan contains the following admonition to utilize the natural landscape to address issues of water resource management:

Marked economy may be effected by laying out parks, while land is cheap, so as to embrace streams that carry at times more water than can be taken care of....thus, brooks which would otherwise be put in large underground conduits at enormous public expense, may be made attractive parkways.

This has a certain Olmstedian ring to it, but it was John Charles Olmsted not his father who first articulated a policy of multi-objective stream management some 95 years ago. While there may be no such thing as "cheap" land anymore, especially in the cities, realizing Olmsted's vision is very much within our ability to implement in the urban and urbanizing environment. That is the path we have set out on in the 24 cities and three counties of the Portland metropolitan region.

Building and Retrofitting Livable Regions

One of Henry David Thoreau's most quoted statements is, "In wildness is preservation of the earth." Ironically, some members of the conservation community, carrying Thoreau's aphorism into battle, have contributed to the unfortunate demonization of the city. Some in the conservation community, I believe, have also deified the so-called "American Dream" of owning a quarter acre, or better yet, a rural homesite in which to commune with nature, as if nature cannot be appreciated in an urban setting. Of course, most of them will then commute to the much-derided city to work. The resultant urban sprawl has consumed vast acreages of prime farm land and productive forest land; fragmented wildlife habitat; destroyed a sense of community; created expanding areas of concentrated poverty in inner cities; and significantly increased the cost of infrastructure, including stormwater management.

Robert Liberty, Director of 1000 Friends of Oregon, provided the following data which illustrate the tremendous consumption of land that is the signature effect of unfettered urban sprawl. Between 1970 and 1990 the Chicago region's population grew by 4% but its land area increased by 50%. Kansas City's population grew by 29% during that same period and its land consumption was 110%. Michigan's population is projected to grow by 12% between 1990 and 2020 while the urbanized areas in that state will increase between 63% and 87%. A study commissioned by the New Jersey legislature concluded that low-density development consumed 130,000 more acres than a more compact urban form would have, at an additional cost of $740 million for roads and $440 million for sewer and water infrastructure.

Perhaps Thoreau's adherents would be better served by a new aphorism, "In livable cities is preservation of the wild." It will only be through the creation or, where necessary, the re-creation of livable cities that we will successfully protect the American landscape and the wilderness. But we cannot hope to create compact, land-conserving, urban forms unless we also ensure our cities are places people want to live, not flee. Without a vibrant, healthy urban Greenfrastructure (an interconnected system of streams, wetlands, Greenspaces and greenways), we will not create, or recreate—retrofit, if you will—livable cities.

Smart Growth and Urban Stormwater Management

There is a growing national movement toward compact urban form, although in truth it is not so much a movement forward as back to a development pattern that is reminiscent of our pre-World War II, non-auto-dominated communities. The weakness of this new Smart Growth movement is the lack of an explicit nexus between higher-density, mixed-use, pedestrian-friendly development and redevelopment on the one hand, and the protection and long-term management of the urban Greenfrastructure on the other. I was recently discussing the Smart Growth movement with one of its adherents in Washington, D.C. and noticed a huge, four-foot by six-foot poster on the wall. Amidst the multi-modal transit schemes, row houses, townhouses and mixed-use developments was a small, three- by five-inch area marked "open space." There were no wetlands, no un-culverted streams, not even a tree in this Smart Growth scenario.

How do we rectify this? First, we can ensure that the next version of that poster has not only the progressive urban planning icons, but also urban waterways with healthy riparian zones, parks that serve multiple purposes–including stormwater and floodplain management–and waterways used by people, fish and wildlife. To promote this vision we need to form new partnerships between non-government organizations (NGOs) and the practitioners of water resource, stormwater and floodplain management. We also need to build new coalitions among NGOs and the grassroots citizen groups that can promote the integration of urban waterway management into the Smart Growth movement.

The Coalition For a Livable Future has successfully brought together unlikely partners in the nonprofit community to integrate stormwater management into local and regional land use programs, and to integrate environmental issues with social and environmental equity concerns. The Coalition For a Livable Future (CLF) is a group of more than 40 nonprofit organizations, working in the Portland-Vancouver metropolitan region, including: the Urban League of Portland which represents low-income communities and people of color; the Community Development Network, an umbrella organization for the region's affordable-housing advocates; Bicycle Transportation Alliance and other alternative transit advocates; several stream groups and watershed councils; and three local neighborhood associations. What many would consider more "mainstream" conservation organizations such as the Audubon Society of Portland and 1000 Friends of Oregon are also CLF members.

Coalition Building: Linking Environmental and Social Concerns to Regional Growth Management

Robert Liberty, director of the 1000 Friends of Oregon, provided the catalyst for the formation of the coalition by bringing Myron Orfield, a Minnesota state legislator, to Portland. Representative Orfield has studied metropolitan regions throughout the U. S. and has documented the "hollowing out" of their urban cores. His maps graphically illustrate the economic disparity that develops between communities as the rapidly growing, sprawling suburbs capture a larger share of the regional tax base—where demand for social services is lowest—while urban neighborhoods with the highest social needs struggle to meet a high demand for services, with a dwindling tax base.

The containment and the reversal of these phenomena was the primary basis for formation of the CLF. While the Portland metropolitan region does not exhibit all the symptoms of urban decline observed throughout the U. S., there were enough signs that we might be headed down the same path of metropolitan decay. The result of Orfield's presentation and subsequent meetings was the writing of a mission statement and development of core principles around which diverse partners could join to become a regional coalition. The coalition's mission statement and objectives were sent to interested organizations and individuals with an invitation to join. Every member organization has been asked to sign an agreement to work not solely on their individual issues, but to commit to promoting the entire integrated package of CLF objectives.

CLF's mission is: *To protect, restore, and maintain healthy, equitable, and sustainable communities, both human and natural, for the benefit of present and future residents of the greater metropolitan region*. The focus of the coalition is to adapt or change government land use, transportation, housing, public investment, and economic and environmental policy through advocacy, research, and public education.

The CLF's objectives are:

1) Protect the region's social and economic health including: preventing displacement of low and moderate income residents and people of color; assuring equitable access to employment and affordable housing throughout the region; and reversing polarization of income.

2) Develop a sustainable relationship between human residents and the region's ecosystems by: changing patterns of urban expansion to more compact neighborhoods; expanding transportation options; and protecting, restoring and maintaining healthy watersheds, fish and wildlife habitat, and Greenspaces both within and outside the Urban Growth Boundary.

3) Assure fair distribution of tax burdens and government investment within the region.

4) Promote a diverse and tolerant society.

5) Increase public understanding of regional growth management issues; develop effective democratic discourse; and promote broader citizen participation in decision-making regarding regional growth issues.

In forming the CLF, we have brought together affordable-housing advocates, those working in the jobs-with-justice arena, and representatives from low-income communities and people of color with the land use and transportation specialists. We are not focusing our attention on urban stormwater management alone, but on our regional growth management program, Region 2040[2], cross-interest education in regional growth issues has been such a tremendously powerful political tool that affordable-housing experts testify before local and regional governments supporting Greenspace protection. By the same token, elected officials hear about affordable housing and urban design issues from the Audubon Society of Portland.

Regional Growth Management: The Context for Coalition Building and Stormwater Management

In addition to Orfield's catalytic role in the formation of the CLF, we were fortunate in having a regional planning program to help focus our energy and develop jointly held principles and policies. Metro, the only directly elected regional government in the United States, has authority over the 24 cities and three counties in the Portland metropolitan region. Metro's charter requires it to undertake regional growth management planning and other issues "of regional significance." Water resource management is one of the regionally significant issues that Metro is required to address, as is housing, transportation, hazard mitigation and, with considerable assistance from coalition members, Greenspaces or natural area acquisition and management. The CLF supports Metro's work where it is coincident with our mission and objectives and addresses deficiencies where necessary. One of the initial deficiencies was weak stormwater and watershed management policies.

To date, the CLF has succeeded in persuading Metro's seven-member council to adopt provisions for fair share, inclusionary zoning for affordable housing (which is, as you might suspect, a controversial issue among local governments); low-income community economic revitalization language in the Regional Framework Plan: and newly adopted floodplain and water quality management regulations that will be applied consistently throughout the metropolitan region. Additional acquisition of natural areas, Greenspaces, and implementation of a regional Greenspaces master plan is also a key element of the framework plan.

Greenspaces to Stormwater Management; Securing the Urban Greenfrastructure

One of the first areas of focus for the coalition was participation in the development of a regional vision. Metro's Future Vision Commission developed, among numerous other recommendations, the following vision for the region:

Integrate urban, suburban, and rural lands in a watershed-wide perspective to ensure reduction in downstream flooding, reduction in wintertime flows and enhancement of summer flows, protection of riparian corridors and wetlands and restoration of fisheries. Any future development within the targeted urban reserves must be sensitive to increased stormwater runoff, erosion, and sources of pollution and flooding downstream communities. An integrated, multiobjective floodplain management strategy shall be developed which recognizes the multiple values of stream and river corridors including: enhanced water quality, fish and wildlife habitat, open space, increased property values, education, flood reduction, aesthetics, and recreation. An interconnected system of streams, rivers, and wetlands that are managed on an ecosystem basis and restoration of currently degraded streams and wetlands are important elements of this ecosystem approach.

We next took on the task of redefining what the region viewed as "infrastructure" in our Regional Growth goals and objectives. We developed an alternative definition, took it to the regional advisory committee of local elected officials and the full Metro Council and the following definition of urban infrastructure was adopted:

Infrastructure: Roads, water systems, sewage systems, systems for storm drainage, telecommunications and energy transmission and distribution systems, bridges, transportation facilities, parks, schools and public facilities developed to support the functioning of the developed portions of the environment. Areas of the undeveloped portions of the environment such as floodplains, riparian and wetland zones, groundwater recharge and discharge areas and Greenspaces that provide important functions related to maintaining the region's air and water quality, reduce the need for infrastructure expenses and contribute to the region's quality of life.

From Greenspace Acquisition to Watershed Management

Even prior to the formation of the coalition, the Audubon Society of Portland and several other groups like The Wetlands Conservancy had worked to create a regionally, interconnected natural areas system. The Coalition for a Livable Future identified Metro as the logical government entity to house a regional natural areas system. Working with numerous citizen groups and local park providers, the coalition was able to persuade Metro Council to establish a Regional Parks and Greenspaces Program at Metro.

Again, coalition-building and partnerships with government agencies at every level were key to this successful grassroots effort. We also had to be creative. We brought in "outside experts" such as Dr. David Goode, Director of the London Ecology Unit in England and *New Yorker* author, Tony Hiss, who wrote about our efforts in national publications. We also invited nationally syndicated columnist Neil Pierce to address our newly established coalition of Greenspace advocates, FAUNA (Friends and Advocates of Urban Natural Areas). We then organized two field tours of the East Bay Regional Park District in Alameda and Contra Costa Counties in the San Francisco Bay area so local elected officials and park professionals in our region could see how a regional park system focused on natural areas can be developed and managed.

In spring of 1989, with funding from the Audubon Society of Portland, local neighborhood groups, U. S. Fish and

Wildlife Service, the U. S. Army Corps of Engineers and a host of other cooperators, Metro commissioned an infra-red photography project for the entire Portland-Vancouver metropolitan region, an area covering 1925 square miles (55 miles north to south and 35 miles east to west). Dr. Joe Poracsky, professor of geography at Portland State University, and his graduate students then digitized this low-level imagery to produce for the first time in our region a map of all remaining natural areas in the Portland-Vancouver metropolitan region[3.]

The result of these efforts was the development of the political will and broad public support at both the local and regional level to establish a regional Greenspaces program at Metro and to pass, with 60% voter approval, a $135.6 million bond measure (from an increase in property taxes) to acquire up to 6,000 acres of Greenspaces. While this acquisition program is a very important tool, the acquisition of 6,000 acres in a region that contains 204 square miles and measures 38 miles east to west and 26 miles north to south is inadequate to protect the regional landscape.

Regulatory Approach: Region-Wide Floodplain and Water Quality Management

During the past three years the Coalition's Natural Resources Working Group has focused its efforts in the regulatory arena and the development of a region-wide Functional Plan, one element of which–Title 3–addresses floodplain and water quality management. Every opinion survey demonstrates tremendous public support for additional regulatory approaches to the protection of water quality and the region's urban waterways. Water quality is viewed as essential to the maintenance of the region's livability and long-term economic health. Protecting urban streams is consistently rated one of the top values in Metro's public surveys: 60 % of the respondents want to protect urban streams, even if it means limiting development.

The Portland metropolitan region has 213 miles of 303 (d)-listed streams and rivers (water quality limited). In addition to these polluted stream miles, 388 miles of streams have "disappeared" by being culverted, routed underground or piped under streets and parking lots. An estimated 8,840 household units in the region are in, or close to, floodplains. Approximately 1,080 units were built in floodplains since 1992. During the February 1996 flood, 189 homes in the region were inundated with water. According to the Oregon Emergency Management Office, the cost of this flood was about $60 million for the three counties in Metro's jurisdiction.

To address these issues the Coalition For A Livable Future has worked with local stream groups and watershed councils, and with Metro staff and elected officials at the local and regional levels to develop a region-wide strategy to address development in the region's floodplains and the degradation of water quality in the Willamette River and its tributaries. One of Metro's most important advisory committees recently recommended to Metro Council that the region's cities and counties be required to do the following, as one element of the region's integrated Growth Concept:

1. Prohibit new development in the floodplains of the region's rivers and streams or, at a minimum, require "balanced cut and fill."

2. Adopt water quality performance standards that focus on retention of vegetated corridors along all of the region's streams, rivers and wetlands. Each city and county will be required to maintain vegetated corridors which provide shade, stabilize banks, trap soil and other runoff before it enters the water and moderate stormwater flow. The vegetated corridors will measure (on each side of the water feature):

   15' for seasonal streams that drain between 50 and 100 acres, on slopes of less than 25%

   50' for perennial streams or rivers that drain more than 100 acres, wetlands and year-round springs if they are in areas where slopes are less than 25%

   200' for streams and wetlands where slopes are more than 25%

3. Adopt Metro's map which delineates all floodplains, wetlands, stream corridors and steep slopes (over 24%) throughout the region or develop local maps which "substantially comply" with Metro's maps.

4. Adopt region-wide erosion control for any new development (no acreage limitation).

5. Adopt Metro's Model Ordinance or develop a local ordinance which substantially complies with Metro's Model Ordinance.

This new regulatory package will be voted on by the full Metro Council in April of this year (1998). Once adopted (scheduled for May of 1998) local jurisdictions will have up to eighteen months to implement the provisions of the Floodplain and Water Quality Management Functional Plan. The recent listing of steelhead by the National Marine Fisheries Service for the lower Willamette River and the Sandy and Clackamas Rivers, all of which are in Metro's jurisdiction, has brought the Endangered Species Act to the Portland metropolitan region in a manner that will assist in the adoption of water resource-oriented growth management policies.

For example, Oregon's Governor, John Kitzhaber and agency directors from the departments of Agriculture, Land Conservation and Development, Division of State Lands, Water Resources, Fish and Wildlife, Geology and Mineral Industries, and Environmental Quality and Water Resources submitted a joint statement that Title 3 of the Coalition's Functional Plan is *an important first step in watershed enhancement...The recent federal endangered species listing of steelhead in the Columbia and Willamette River systems elevates the significance of habitat protec-*

tion practices at the local government level. . .We offer the following additional recommendations: add a provision for setback buffers in headwater areas, preferably a minimum of fifty feet. We encourage Metro's early adoption of strong Title 3 policies and implementing measures so that progress can be made soon on the larger work envisioned by chapters 4 and 5 of Metro's Regional Framework Plan. A letter of this nature is unprecedented in the Portland metropolitan region.

Next Steps

The Coalition will continue to focus its efforts on the chapters of the Regional Framework Plan that require consistent, region-wide stormwater management: mandated comprehensive watershed planning for all the region's watersheds within Metro's jurisdiction; development of policies to reduce landslide hazards; and development of a regional fish and wildlife habitat protection program that would ensure an adequate program in every city and county within Metro's jurisdiction. We will also work to implement the Greenspaces Master Plan, which will include an update of the 1989 infrared Greenspaces inventory, and establish plans for a regional interconnected Greenspace system based on maintaining the region's biodiversity and wildlife corridors.

References

1. More information on the Coalition For a Livable Future can be obtained at the Coalition's offices at 534 SW Third Avenue, Suite 300, Portland, OR 97204 (phone: 503-294-2889, email: zack@friends.org).

2. For more information about Metro's Region 2040 growth management planning process contact: Elaine Wilkerson, Director Growth Management Services, Metro, 600 NE Grand, Portland, OR 97232.

3. Metro has a Growth Management Hotline, 503-797-1888 and a website, www.metro-region.org. For more information about their GIS mapping, contact Metro, Data Resource Center 503-797-1742 or Metro's website,

The Use of Retention Basins to Mitigate Stormwater Impacts to Aquatic Life

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Abstract

Physical habitat and biological measurements were taken in nontidal streams below eight stormwater management pond facilities (BMPs) during the spring of 1996. Two of the sites were predominantly in commercial land use while the remaining six sites were in residential land use. The results were compared to 33 sites with no stormwater controls. Three replicate macroinvertebrate samples were collected in riffle habitats using a kicknet. Biological quality was determined from six metrics using 100-organism subsamples identified to the species level. Physical habitat quality was determined from 12 metrics that defined the condition of the channel, stream bank, and riparian zone. These biological and physical habitat metrics were compared with mean values derived from three reference sites to produce summary index scores for each site, reported as "percent of reference." The overall macroinvertebrate community, as measured using a composite of all six biological metrics (Community Index), was not significantly different between BMP and non-BMP sites. A similar result was found using a composite of three metrics that characterized pollution-sensitive organisms (Sensitive Species Index). The BMPs did not prevent the almost complete loss of sensitive taxa (e.g., mayflies, stoneflies, and caddisflies) after development. Further, the BMPs did not attenuate the impacts of urbanization once the watershed reached 20% impervious cover. Data are needed to determine whether these controls would attenuate impacts at lower levels of development (5-15% impervious cover). Half of the BMP sites had Habitat Index scores comparable to the reference condition, indicating mixed results with regard to the effectiveness of the BMPs in protecting physical habitat. These results suggest that following management actions may be needed: (1) modifications to traditional urban designs that reduce impervious cover and preserve natural features (e.g., "conservation design"), (2) modifications to stormwater retention basin designs (e.g., expanded capacity, constructed wetlands), and (3) the restoration and preservation of forest cover along stream channels, especially along intermittent streams and first and second order perennial streams.

A data set of this size should not be used to derive definitive conclusions regarding the ability of stormwater controls to protect aquatic life and physical habitat. This study characterized the condition of only eight sites, and the stormwater management design criteria varied between the sites. The lack of comparable studies of other regions of the U.S., and the use of other measures of stream condition below stormwater controls suggest the need for additional research.

Introduction

Over the last 90 years, the population of the United States has increased 300%, from 76 million in 1900, to 249 million in 1990 (United States Census 1996). This period has also seen a dramatic shift in the way people live and use the land. In 1900, the majority of the U.S. population (60%) lived in rural areas, while in 1990 the majority (75%) lived in urban areas. This trend continues today although at a slower rate. But even as the rate levels off, roughly three-fourths of the estimated 25 million people that will be added to the population over the next decade will likely live in urban areas. Delaware's population has experienced a similar rate of population increase (185,000 to 666,000) and shift in land use over this period.

This change in demographics and land use has brought about profound changes in the physical, chemical, and biological integrity of nontidal streams in Delaware. The objective of this research was to determine the effectiveness of stormwater controls, principally retention basins, to protect stream resources after urbanization. This study focused on wadeable, nontidal streams and the use of macroinvertebrates and physical habitat as indicators of stream ecological health.

Impervious surfaces (roads, parking lots, rooftops, driveways, sidewalks, etc.) increase peak flows during storm events and reduce base flows during droughts. Urbanized watersheds with 20-30% impervious cover were found to have 10-15 times the frequency of small flood events (1-year recurrence interval) compared to nonurban watersheds; large flood events (100-year) doubled in size after urbanization (Hollis 1975). This change in stream hydrology affects the physical structure and stability of stream channels through accelerated erosion and sediment deposition. The replacement of native riparian vegetation (e.g., trees) with lawns, parks, golf courses, and structures (e.g., buildings, bridges) along stream channels and floodplains further impact the geomorphology of urban streams.

Water quality contaminants in stormwater (metals, nutrients, organics) further stress aquatic life. Exceedences of dissolved oxygen (DO) criteria occur in streams and ponds through nutrient enrichment and the removal of shade. In a recent survey, unshaded stream channels in Delaware exceeded the State's acute criteria for DO and temperature 73% and 38% of the days, respectively, during the Summer of 1993 (Maxted et al., 1995). Both physical and chemical factors associated with urbanization contribute to the overall biological condition of urban streams.

Aquatic organisms, principally fish and macroinvertebrates, are commonly used to assess the ecological condition of streams, and several researchers have used them to assess the impacts of urbanization (Shaver and Maxted 1995, Jones and Clark 1987, Klein 1979, Limburg and Schmidt 1990, Pedersen and Perkins 1986, Booth and Jackson 1994, Weaver and Garmen 1994, and Garie and McIntosh 1986). These studies have recently been summarized (Schueler 1994). What is generally lacking are studies which use aquatic organisms to evaluate the effectiveness of stormwater controls.

The water quality impacts of stormwater runoff are fairly well documented, as is the ability of a variety of stormwater management facilities to provide water quantity control and water quality treatment. There has been an inherent assumption that water quality treatment and pollutant capture directly translate into aquatic life protection. This assumption has never been validated. In addition, stormwater treatment facilities effectively remove pollutants, but the level of performance is highly variable and needs to be expressed in ranges rather than in specific levels of treatment. At great expense, large amounts of data covering many stormwater events and constituents are needed to make reasonable statements regarding the performance of BMPs in removing pollutants (Urbonas, 1995).

Water quality data can also present problems in terms of data accuracy. Stormwater management facilities often have multiple inflow points and may receive overland flow which makes data collection difficult. Monitoring each inflow point and the facility outfall increases the potential for error in data collection and analysis. Coupled with the need to sample multiple storm events over different seasons and different years, these factors make it difficult to accurately assess the performance of the BMP. These factors also affect the overall cost of monitoring.

What is needed is a simple, long-term approach to system assessment which minimizes the cost of data collection and provides a framework for evaluating the effectiveness of controls. Presented in this paper is a framework for assessing the ecological health of aquatic ecosystems and the performance of stormwater facilities using living resources, in this case aquatic macroinvertebrates. While evaluating stream ecological health using aquatic organisms is widespread, the evaluation of stormwater facility performance using this approach is fairly new. Preliminary results of the present study have been summarized previously (Maxted and Shaver, 1997).

Methods

The heavily urbanized piedmont region of northern Delaware was selected for study. Data collected at 33 sites with no BMPs in the catchment were compared with eight sites sampled below modern stormwater retention basins (Figure 1). As of 1984, about half the piedment region (48%) was in urban land use, 33% was undeveloped, and 19% was in agriculture. Stormwater controls have only recently been included as part of new developments in the region. Therefore, the data collected at the 33 non-BMP sites represent conditions that existed before the implementation of regulatory programs for controlling stormwater runoff. The land use conditions in the watersheds above the 33 non-BMP sites covered the full range of urban land use from relatively undeveloped watersheds with less than 10% impervious cover to heavily urbanized watersheds with greater than 30% impervious cover. Sampling sites were

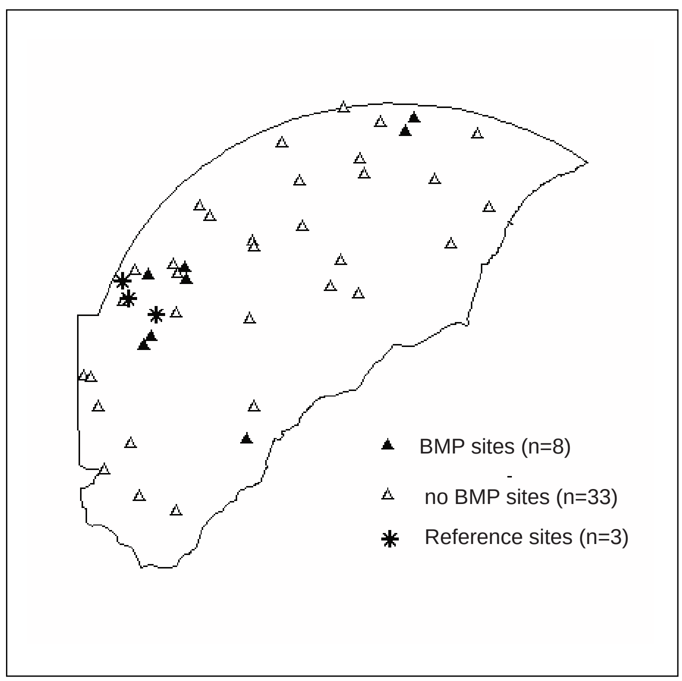

Figure 1. Locations of sampling sites within the northern piedmont region of Delaware.

located 100 meters below the BMP discharge to minimize the immediate influence of the discharge on the stream and the influence of construction and maintenance activities related to the BMP itself (grading, mowing, habitat disturbance, etc.).

The 33 non-BMP sites were sampled in the fall of 1993, while the eight BMP sites were sampled in the spring of 1996 (between May 2nd and June 6th, 1996). The metrics used to summarize the biological data were not considered to be sensitive to seasonal differences between the fall and the spring, and thus allowed for this comparison.

Macroinvertebrate samples were collected using a 1-meter^2 kick net (750 µm mesh). Each sample was a composite of two collections of a 1-meter^2 area of riffle, combined in a sieve bucket (600 µm mesh). Three replicate collections were made at each site while moving progressively upstream. A single 100-organism subsample was removed from each sample and identified to the species level. Six metrics were derived for each sample: taxonomic richness (TR); richness of the orders of ephemeroptera, plecoptera, and trichoptera (EPT); % EPT abundance (% EPT); % Chironomidae (% C); % dominant taxon (% DT); and the Hilsenhoff Biotic Index (HBI) (Table 1).

Habitat quality assessment included measures of the channel, stream bank, and riparian zone. Each assessment consisted of the visual characterization of a 100-meter segment of the stream using the following 12 parameters. Numerical scores, out of a possible 20 points, were assigned to each parameter.

CM - channel modification: the degree of engineering of the channel shape (e.g., channelized) and the extent to which it meanders.

BSC - bottom substrate/available cover: the amount and variety of submerged stable habitat throughout the stream segment (e.g., riffles, logs, snags, aquatic plants, root-wads along banks, etc.).

E - embeddedness: the degree to which the substrate is surrounded or covered by fine sediment.

Table 1. Biological Metrics Used to Derive Summary Index Scores for BMP and non-BMP Sites.

Metric Name	Description	Type
taxonomic richness	total number of unique taxa	richness
EPT* richness	total number of EPT taxa	rich/tolerance
% EPT abundance	% of sample that are EPTs	tolerance/comp
% dominant taxon	largest % of a single taxon	composition
% Chironomidae**	% of sample from this group	tolerance
Hilsenhoff (HBI)	composite tolerance by taxon	tolerance

* EPT - the orders ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies); high richness or relative abundance indicates high quality.

**Chironomidae - family of midges; high relative abundance indicates low quality.

RQ - riffle quality: the dominant substrate found in riffles; cobbles are the most desirable, boulders and gravels are the least desireable.

FR - frequency of riffles: the abundance of riffle areas in the stream segment.

SD - sediment deposition: the degree to which new sediment is deposited in the stream channel as evidenced by islands, point bars, and sand and silt covering stable habitats.

V/D - velocity/depth: the presence of four categories of flow regime; slow and deep, slow and shallow, fast and deep, fast and shallow.

BS - bank stability: the proportion (%) of stream banks that show evidence of recent and active erosion.

BV - bank vegetative type: the dominant vegetation on the stream bank; trees and shrubs being most desirable, grasses being the least desirable; left and right banks scored separately and then combined.

S - shading: the percent of the stream surface that is shaded throughout the day.

RZ - riparian zone width: the width of the riparian zone showing little or no evidence of human activity; left and right sides scored separately and then combined.

HCI - Habitat Comparison Index: summary index of habitat quality; individual parameter scores summed and divided by a reference value; index values expressed as "percent of reference."

Three summary index scores, two biological and one habitat, were derived for each site following procedures developed by EPA (Plafkin, et al., 1989). Three reference sites were sampled during the same seasonal period as the sampling sites and used to derive index scores reported as "percent of reference." Habitat Index scores were determined by comparing the total habitat score for each BMP site with the mean total score for the three reference sites. Community Index (CI) scores were determined by comparing all six biological metric values for each site with the mean values from the three reference sites. The CI was used to define the overall quality of the macroinvertebrate community. The Sensitive Species Index (SSI) scores were determined using the three biological metrics (EPT, % EPT, and HBI) that define the components of the community that are the most sensitive to organic pollution. Mean CI and SSI scores for each site were determined from the CI and SSI scores from the three replicate samples.

The biological data were plotted against % impervious cover estimates determined for the catchment above each site. Land use was determined from digitized 1992 land use data. Percent impervious cover estimates were made by multiplying the area of each land use category by the % impervious cover estimate for that category, as published by the U.S. Department of Agriculture (USDA 1986), summing the values for all the land use categories, and then dividing the total % impervious area by the total area for the catchment. The CI biological index values were plotted against the HCI habitat index values to further characterize the habitat quality of the BMP sites. Mean values differing by more than one standard deviation were defined as statistically significant.

BMP Site Selection

BMP site selection employed a variety of information sources including an existing stormwater facility inventory and discussions with individuals familiar with a number of facilities. The stormwater facility and stream criteria used to select BMP sites are listed below. Eight sites met these criteria and were selected for study; two sites were predominantly in commercial land use while the remaining six sites were in residential land use (Table 2). The two commercial sites and one residential site met modern design standards for peak control of the two-, ten-, and 100-year storms, and extended detention of the first inch of runoff. Four residential sites were designed for control of the ten-year storm only. One residential site was located in the main channel of Jenny's Run below five separate retention basins that captured approximately 75% of the the urban land use in the catchment (Table 2).

Stormwater facility criteria:

- Facilities had to be retention or detention basins, so that one specific type of BMP (e.g., ponds designed for stormwater control) could be evaluated.
- To the greatest extent possible, the facility had to meet current design criteria which included peak rate control (two-, ten-, 100-year storms) and water quality performance (24-hour detention for the first inch of runoff). If a sufficient number of facilities were not found, due to the recent nature of the State Stormwater Management Program (effective date July, 1991), older retention ponds serving a development were considered.
- Facilities had to be at least two years old. The concern with newer facilities was that there was potential for construction-related stream impacts. If a new facility had significant instream impacts, the cause of the impact might be related to excess runoff and sedimentation during construction rather than the performance of the BMP.
- Impervious cover in the catchment to the facility had to be at least 20%. This would answer the initial question concerning the effectiveness of BMPs in already urbanized areas. Based on the results of this study, future studies might address the question of the effectiveness of BMPs at earlier stages of urbanization (e.g., 5-15% impervious cover).

Receiving stream criteria:

- Discharge from the BMP represented the predominant flow in the stream.
- Riparian zone had native vegetation (e.g., trees, wooded, and shaded) and was not directly impacted by human activities. This criterion might be difficult to achieve in the heavily urbanized piedmont region of Delaware.
- The receiving stream had perennial flow. This criterion might be difficult to achieve since the streams below individual retention basins are first order streams with fairly small drainage areas.
- Riffles with a cobble substrate were common.

Results

The mean EPT richness (EPT), % EPT abundance (% EPT), % Chironomidae (% C), and Hilsenhoff Biotic Index (HBI) metrics were significantly different between the BMP sites and the reference sites (Table 3). This indicated that none of the BMP sites prevented a shift in the macroinvertebrate community from one dominated by pollution-sensitive organisms to one dominated by pollution-tolerant organisms. Taken together, sites below BMPs had a low proportion of the pollution-sensitive organisms (14% EPT) and a high proportion of pollution-tolerant organisms (54% Chironomidae), while the community at reference sites was almost exactly the opposite (Table 3). The BMP sites had half the mean HBI value of the reference sites, indicating a shift at the species level as well. Similar results were found using the two summary biological indi-

Table 2. BMP Facility Data

Site	Land Use	% Impervious Cover	Drainage Area	Development
BMP 1*	Residential	25	88.0 acres	Corner Katch
BMP 2**	Commercial	22	83.0 acres	Brandywine Com
BMP 3**	Commercial	65	36.0 acres	Core States
BMP 4**	Residential	30	32.0 acres	Hunt at Louviers
BMP 5*	Residential	28	383.0 acres	Veranda
BMP 6*	Residential	31	107.0 acres	Limestone Hills
BMP 7*	Residential	30	157.0 acres	Chestnut Hills
BMP 8***	Residential	23	330.0 acres	Jenny's Run

* Project design based on peak control of the ten-year storm only.
** Project design based on peak control of the two-, ten-, and 100-year strom, in addition to 24-hour extended detention for the first 1" of runoff.
*** Site in main stream of Jenny's Run; considered stormwater flow from more than one development site.

Table 3. Mean Values for Six Biological Metrics and Two Summary Indices Below Eight BMPs; Taxonomic Richness (TR), EPT Richness (EPT), % EPT Abundance (% EPT), % Chironomidae (% C), % Dominant Taxon (% DT), Hilsenhoff Biotic Index (HBI), Community Index (CI), and Sensitive Species Index (SSI); Standard Deviation Appears in Parenthesis.

	samples	Biological Metrics						(% of reference) Summary Indices	
Site	N	TR	EPT	% EPT	% C	% DT	HBI	CI	SSI
BMP 1	3	35 (5)	7.3 (0.6)	18 (6)	54 (6)	15 (5)	5.2 (0.4)	49 (3)	26 (6)
BMP 2	3	21 (6)	2.0 (1.7)	26 (19)	52 (20)	29 (7)	6.1 (0.4)	35 (15)	15 (17)
BMP 3	3	31 (3)	1.7 (0.6)	2 (1)	71 (10)	27 (11)	5.8 (0.4)	33 (3)	7 (6)
BMP 4	3	26 (6)	6.0 (1.0)	17 (9)	60 (22)	27 (14)	5.3 (0.7)	39 (18)	18 (18)
BMP 5	3	19 (3)	0.0 (0.0)	0 (0)	37 (24)	51 (26)	7.1 (0.5)	25 (6)	0 (0)
BMP 6	3	22 (7)	6.7 (1.1)	14 (2)	38 (36)	47 (22)	6.4 (0.8)	31 (9)	7 (13)
BMP 7	1	29 (-)	5.0 (-)	9 (-)	75 (-)	22 (-)	5.4 (-)	35 (-)	11 (-)
BMP 8	3	23 (3)	7.7 (1.5)	26 (8)	60 (8)	20 (5)	4.7 (0.5)	51 (12)	33 (20)
all BMPs	28	25 (7)	4.5 (3.0)	14 (12)	54 (21)	30 (17)	5.8 (0.9)	38 (12)	15 (15)
Reference	10	24 (4)	10.3 (1.8)	56 (12)	14 (13)	24 (4)	2.9 (0.6)	100	100

ces. The mean Community Index (CI) scores for the BMP sites ranged from 25-51% of the reference condition while the mean Sensitive Species Index (SSI) scores ranged from 0-33% (Table 3).

Mean values for the biological metrics and summary indices for the eight BMP sites were compared to 21 non-BMP sites with similar land use (Table 4). Only non-BMP sites with greater than 20% impervious cover were considered in order to provide a similar level of urban development between the two groups of sites. There was no significant difference between the two groups of sites for the EPT, %EPT, and %C metrics, as well as the CI and SSI index values (Table 4). Both the BMP and non-BMP sites were significantly different from the reference condition for most biological metrics, indicating that neither group of sites approximated conditions found in undeveloped watersheds (Table 4). While the BMPs appeared to increase the relative abundance of EPTs (i.e., % EPT), it had no effect on either taxonomic richness of EPTs (i.e, number of unique EPT taxa) or the HBI; both are good indicators of pollution tolerance.

A lack of biological improvement with the eight BMP sites was observed when the data were plotted against % impervious cover. No improvement in biological condition was observed using either the Community Index (Figure 2) or the Sensitive Species Index (Figure 3), as compared to sites without BMPs. BMPs did not prevent the loss of sensitive species found at reference sites. The degree of urbanization did not appear to affect biological conditions at the BMP sites. The one BMP site with 65% impervious cover had a similar biological condition to the seven sites with 22-32% impervious cover.

Half of the BMP sites (BMP2, BMP3, BMP6, and BMP7) had habitat scores less than 90% of reference, indicating physical habitat impairment (Table 5). These sites exhibited the physical characteristics of urban streams with no controls, indicating that the BMPs were not effective at eliminating the impacts of urbanization. The impacts were most often associated with bank instability and channel sedimentation. The other half of the sites (BMP1, BMP4, BMP5, and BMP8) had habitat conditions similar to the reference sites (i.e., greater than 90% of reference). It appeared that some of the BMPs provided stable channel characteristics, although there was no pattern related to BMP design type or drainage area. The three sites that had the highest physical habitat quality (BMP1, BMP4, and BMP8) represented the full range of both BMP design type and drainage area. The level of impairment, both physically and biologically, was also illustrated when biological quality was plotted against habitat quality (Figure 4).

Discussion

Retention and detention basins designed to control stormwater did not protect aquatic life from the adverse

Table 4. Comparison of Mean Values for Six Biological Metrics and Two Summary Indices Between Reference Sites and Sites With and Without Stormwater BMPs; Taxonomic Richness (TR), EPT Richness (EPT), % EPT Abundance (% EPT), % Chironomidae (% C), % Dominant Taxon (% DT), Hilsenhoff Biotic Index (HBI), Community Index (CI), and Sensitive Species Index (SSI); Standard Deviation Appears in Parenthesis.

	samples	Biological Metrics						(% of reference) Summary Indices	
Site	N	TR	EPT	% EPT	% C	% DT	HBI	CI	SSI
Reference	10/3	24 (4)	10.3 (1.8)	56 (12)	14 (13)	24 (4)	2.9 (0.6)	100	100
BMP	28/8	15 (7)	4.5 (3.0)	14 (12)	54 (21)	30 (17)	5.8 (0.9)	38 (12)	15 (15)
no BMP*	29/21	20 (5)	4.7 (2.7)	27 (18)	28 (23)	27 (18)	5.1 (1.2)	36 (14)	14 (15)

* only urban sites with 20-65% impervious cover included

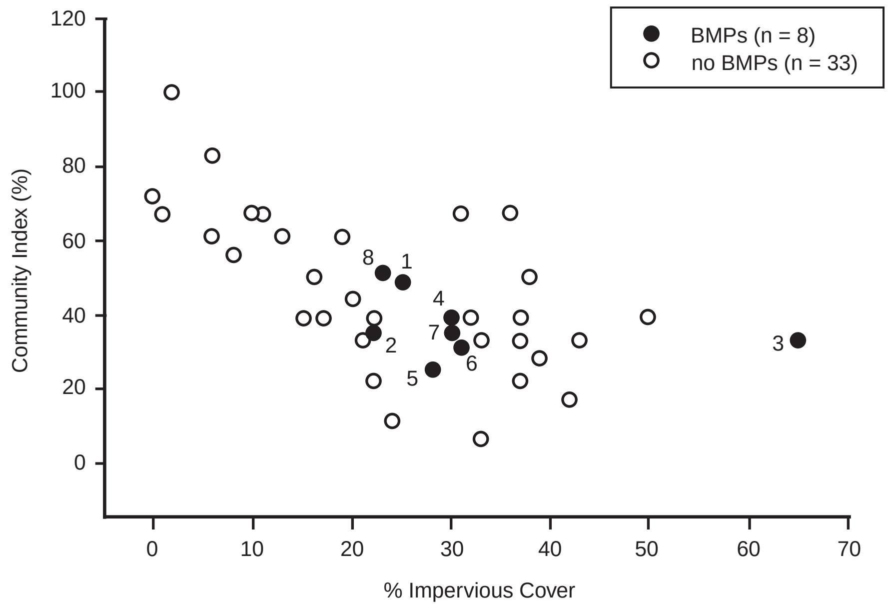

Figure 2. The effects of urbanization on the macroinvertebrate community; numbers denote BMP sites.

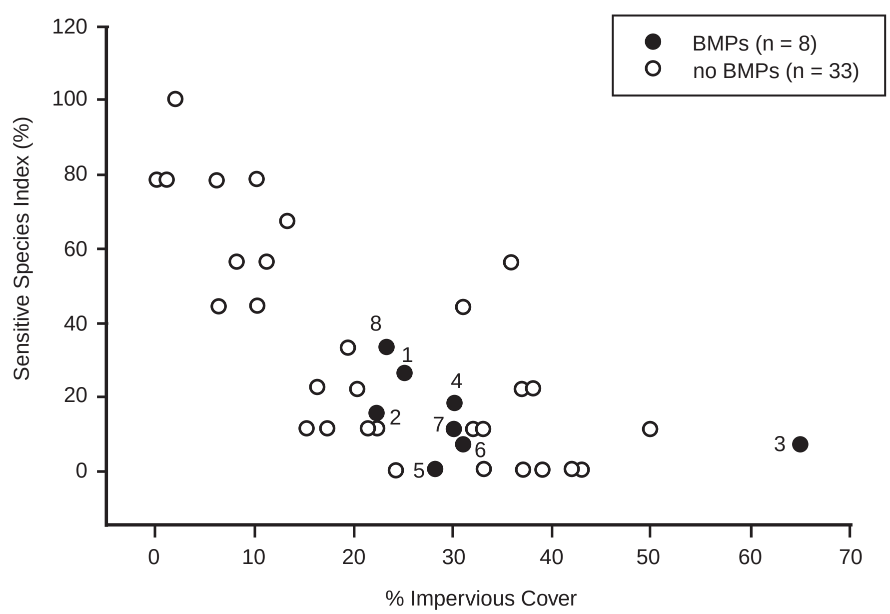

Figure 3. The effects of urbanization on sensitive species of macroinvertebrates; numbers denote BMP sites.

Table 5. Habitat Metric Scores Below Eight BMPs; Habitat Comparison Index (HCI) Reported as % of Reference; See Text for Abbreviations.

Site #	CM	BSC	E	RQ	FR	SD	VD	BS	BV	S	RZ	Total	(%) HCI
BMP 1	12	19	17	16	18	16	10	13	10	20	20	171	100
BMP 2	20	6	16	13	9	5	7	6	12	18	20	132	77
BMP 3	15	13	11	13	12	7	9	11	10	15	12	128	75
BMP 4	19	18	18	14	19	16	10	18	18	16	20	186	109
BMP 5	19	19	9	11	19	6	10	20	10	16	17	156	91
BMP 6	17	18	12	18	14	8	10	6	4	19	20	146	85
BMP 7	11	5	19	10	1	6	11	20	10	17	13	123	72
BMP 8	18	19	19	17	19	16	10	11	10	20	20	179	105
Reference	17	17	18	15	17	12	10	11	17	16	20	171	100
Possible	20	20	20	20	20	20	20	20	20	20	20	220	-

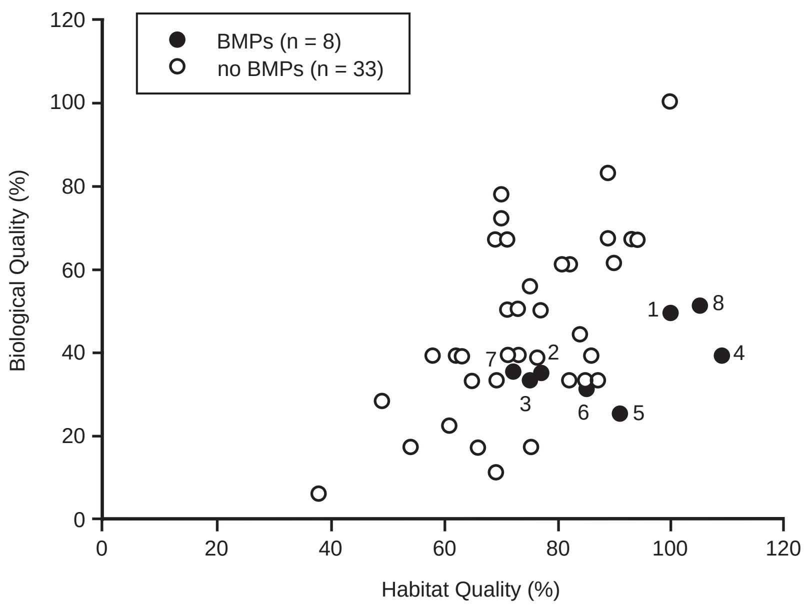

Figure 4. The effect of habitat quality on biological integrity; biological quality measured using the Community Index; numbers denote BMP sites.

effects of urbanization. This may be due to factors related to the design and construction of the BMPs themselves, such as temperature, water quality (road salt, contaminants), inadequate controls during construction, and age of the facility. Modern extended detention basins are not designed to control dissolved contaminants and temperature extremes. Constructed wetlands added on to retention ponds may be needed to remove dissolved contaminants and attenuate temperature extremes.

Half of the BMP sites did not provide habitat conditions comparable to reference areas, indicating that the ponds did not maintain stable channel characteristics. Further study is needed to define the controlling factors. One of the most important factors contributing to both the physical habitat and biological impacts we observed may be related to hydrologic modification of the watershed. Ponds mitigate, to some degree, the hydrologic changes resulting from conventional urbanization, but they cannot reduce the significant increase in total volume of post-development stormwater traveling through the watershed. Efforts to simulate pre-development hydrology (through conservation design) may be necessary to protect aquatic resources.

The impacts we measured 100-200 meters below the facility may be attenuated with distance downstream. There was some indication, from visual observations in the field, that biological conditions improved with increased distance from the discharge. More data are needed to determine the areal extent of the impacts in streams we have reported below stormwater detention facilities.

The effect of the ponds themselves on stream ecology should not be overlooked. The aquatic community is often different upstream and downstream of ponds, even in undeveloped forested watersheds. While one of the three reference sites had a series of old farm ponds in the watershed, two did not. Ponds effectively convert inorganic carbon and nutrients to organic matter through photosynthesis. This fine particulate organic matter (FPOM) discharged to the stream during runoff events is a preferred food source for invertebrates and fish tolerant to organic pollution. The effect on living resources we observed and quantified below the eight BMP ponds may also be related to the construction of the ponds themselves. The important conclusion remains, however, that ponds constructed to treat stormwater were inadequate to protect aquatic life.

Site selection was more difficult than we first anticipated. Many of the streams that received a discharge from a retention or detention pond were too small to sample, had a degraded riparian zone (unshaded), or discharged directly to a larger tributary. Many of the BMP sites not selected for study had small drainage areas that would have had intermittent flow even under pre-development conditions. It was difficult to find a representative sample of stormwater management BMPs that met modern design criteria due to the relative short time between the initiation of the Stormwater Management Program in Delaware and this monitoring effort. The only sites meeting the state's stormwater management requirements in terms of when they were constructed and their design criteria were the two commercial sites and one residential site. The other residential sites were selected because retention ponds are a preferred practice under the new state program.

Construction-related impacts must be expected as a result of increased stormwater discharges and elevated sediment loadings. There has to be a period of time after construction, and before measurements should be taken, to assess the response of a receiving system to site development and stormwater management facilities. We can make recommendations, such as a period of two years used here, but that recommendation must be considered "preliminary" and subject to variation around the country due to differences in climatic and other factors.

The importance of riparian zone protection and restoration cannot be stressed too much. More effective management of riparian zones must be provided if receiving systems are to acheive the structure and function of undisturbed systems. The greatest difficulty in site selection was finding BMPs that discharged to streams with undisturbed riparian areas. This was not surprising given the results of a recent statewide survey in which 87% of the nontidal stream miles were found to have degraded physical habitat (Delaware DNREC 1994). The environmental benefits of control efforts (both structural and non-structural) will be reduced if we fail to restore and protect riparian habitat.

This study represented a different approach to assessing BMP effectiveness as compared to chemical monitoring. Traditional approaches that focus on chemical contaminants determine aquatic life use support based on pounds of pollutants removed and compliance with chemical criteria. Our approach looked directly at the aquatic organisms the controls were designed to protect. Living resources are the only direct measure of aquatic life condition. All others, including physical habitat, are surrogates that may underestimate or overestimate the true condition of living resources.

Some have argued that undeveloped forested watersheds should not be used as the reference condition for evaluating the performance of stormwater controls. They also assert that fundemental changes in land use in urban watersheds justifies the establishment of a lower quality "urban stream standard" for aquatic resources. They feel that this lower standard is needed because streams in urban watersheds will never achieve such a high level of quality even with extensive land use and stormwater controls. Further, they claim that urban land uses impact only a small percentage of stream resources in most regions.

We reject these arguments for several reasons. First, such an "urban stream standard" would be nearly impossible to set. How would such a level of "acceptable" or "achievable" quality be determined? Whatever approach was selected would undoubtedly be influenced by political rather than scientific factors. Second, conservation design practices coupled with structural and non-structural controls do not yet exist over extensive areas. We, therefore, have no way of knowing whether the application of these controls might achieve a higher level of ecological quality. Third, if we were to set a lower standard, we would eliminate a principal incentive for challenging and testing the standard. And lastly, urban areas affect an ever-increasing proportion of nontidal streams, particularly intermittent, first, and second order streams. Urban sprawl affects aquatic resources far away from city centers, extending the proportion of streams affected by urbanization. While roughly half of the piedmont region of Delaware is in urban land uses, it adversely affects nearly all of the 270 miles of nontidal streams.

It is too early to panic, as additional studies are needed. Our results should best be described as preliminary. If further studies confirm these results, BMP design criteria will have to be reconsidered to provide a greater level of protection to receiving systems. Similar data are needed at more sites in the piedmont region of the Mid-Atlantic U.S., before making definitive conclusions on the effectiveness of stormwater basins in protecting aquatic life and physical habitat. Data are also needed for various types of urban designs (e.g., conservation design), various levels of impervious cover, and various types of BMP designs, including the three presented here and the use of constructed wetlands. The ultimate question remains to be answered: Can urban developments that incorporate available control technologies be cost-effective and marketable, while protecting living resources?

Urban Retrofit Opportunities

What are the implications of this research with regard to areas already undergoing various degree of urbanization?

First, this research indicates that retention basins are not sufficient to protect living resources. It is likely that changes are also needed in the way urban areas are designed and constructed in the first place. It should be no surprise that ponds added on to conventional urban developments, where nearly 100% of the development site is modified for human uses, did not protect aquatic life. The concept of "conservation design" used in conjunction with structural and non-structural controls may be necessary. Conservation design encompasses a range of alternative design practices that reduce impervious surfaces (e.g., reduced roadway width, reduced setbacks), preserve sensitive natural features (woodlots, wetlands, floodplains), and reduce collection system infrastructure (grassed swales, smaller and more numerous retention areas). The State of Delaware, in conjunction with the Brandywine Conservancy, has recently completed a manual on conservation design (Delaware DNREC 1997).

Second, protecting intermittent, first, and second order perennial streams needs to be mentioned since their importance is often overlooked. From a developmental perspective, these streams are often filled, piped, rerouted, or otherwise altered. We then, through regulatory programs, attempt to protect third and higher order streams and their associated resource values. It may not be possible to protect the values of these higher order streams and rivers unless we first protect the headwater streams at the top of the watershed.

Third, the design of stormwater retention basins may need to be modified to enhance their performance, particularly with regard to dissolved contaminants and temperature effects. It should also be no surprise that ponds may not be sufficient, by themselves, to attentuate the water quality, hydologic, and biological effects of urbanization. In fact, the ponds themselves may be contributing to the problem. Conservation design in conjuction with extended detention and constructed wetlands may be necessary to protect stream ecological health. Further, we may want to make a requirement that all ponds be "off-line" from wetlands, intermittent streams, and first and second order perennial streams to prevent the direct impact that the BMPs have on existing aquatic resources.

Fourth, riparian restoration should be implemented immediately, which would provide significant benefits to stream health even in heavily urbanized areas. Most of the BMP sites visited during site selection could not be studied because the streams they discharged to lacked native riparian vegetation (e.g., trees). They most often consisted of backyards or parks with grassed areas and few trees. Through public education and the establishment of easements, these areas should be preserved and restored as natural wooded riparian corridors. This will be necessary, eventually, even after the implementation of structural and non-structural controls, to protect aquatic resources. Since natural revegetation with trees can take many years, efforts should be initiated now.

All of these objectives will need to be met if streams in urban areas are to attain the structure and function of natural systems. Since prevention is often more effective and less expensive than treatment, the most critical watersheds are those in the early stages of urbanization (5-15% impervious cover). The need to focus attention on these watersheds is important because impacts are often permanent once the urban land use is in place. Additional research and monitoring is especially important in these areas while we also attempt to retrofit conditions in already developed watersheds.

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Assessing the Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds

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Introduction

The health and well-being of the aquatic biota in surface waters is an important barometer of how effectively we are achieving the goals of the Clean Water Act, namely the maintenance and restoration of biological integrity and the basic intent of water quality standards. States designate water bodies for beneficial uses (termed designated uses) that along with specific chemical, physical, and biological criteria, assure the protection and restoration of aquatic life, recreational, and water supply functions and attributes. Ohio Environmental Protection Agency (EPA) employs biological, chemical, and physical monitoring and assessment techniques to assess the status of these beneficial uses and to satisfy three major objectives:

1) determine the extent to which use designations assigned in the Ohio Water Quality Standards (WQS) are either attained or not attained;

2) determine if use designations assigned to a given water body are appropriate and attainable; and,

3) determine if any changes in key ambient biological, chemical, or physical indicators have taken place over time.

An integrated biological, chemical, and physical monitoring and assessment approach has been used to support all relevant water quality management activities, including urban stormwater issues, within Ohio EPA during the past 18 years. The details of this process have been extensively described elsewhere (Ohio EPA 1987a,b; Ohio EPA 1989a,b; Yoder and Rankin 1995, 1998).

Urban Watersheds

Urban watersheds in Ohio exhibit a familiar legacy of aquatic resource degradation. Few, if any, ecologically healthy watersheds exist in the older, most extensively urbanized areas of Ohio (Yoder 1995) and no headwater streams (i.e., draining <20 mi.^{2}) sampled by Ohio EPA during the past 18 years in these areas have exhibited full attainment of the Warmwater Habitat (WWH) use designation (Yoder and Rankin 1997).

The activities that have the greatest impacts on aquatic life in Ohio's urban watersheds include the wholesale alteration of watershed hydrology, loss and degradation of riparian habitat, direct instream habitat degradation via channelization, culverting, and interceptor sewer line placement, excessive sedimentation resulting from land disturbance activities and stream bank erosion (strongly linked to riparian encroachment), and contributions of excessive nutrients, oxygen-demanding wastes, and toxic chemical pollutants via urban runoff, point source discharges (both permitted and unpermitted), and spills and other releases. According to the 1996 Ohio Water Resource Inventory (305[b] report), urban and suburban sources are responsible for aquatic life use impairment in nearly 1000 miles of Ohio streams and rivers and more than 23,000 acres of lakes, ponds, and reservoirs (Ohio EPA 1997). These activities also threaten existing full use attainment in nearly 160 miles of streams and rivers and may pose a potential problem in more than 4380 miles of streams and rivers that have not yet been fully monitored and evaluated. These are also one of the fastest growing threats as urban and suburban development extends further into rural watersheds.

While much attention has been paid to toxic substances in urban runoff, evidence suggests that sedimentation is the most pervasive *single* cause of impairment associated with nonpoint sources in Ohio. While sediment deposition in lotic and lentic environments is a natural process, it becomes a problem when the capability of the ecosystem to "assimilate" the sediment load is exceeded. The effects of sediment on aquatic life are the most severe in the ecoregions of Ohio where: (1) upland erosion and runoff are moderate to high, (2) clayey silts that attach to and fill the interstices between coarse substrates predominate, and (3) streams and rivers lack the ability to expel the finer grained sediments from the low-flow channel because of instream and riparian habitat degradation. Estimates of gross erosion *alone* are not consistently correlated with adverse impacts to aquatic communities, although this is a frequently used indicator for prioritizing nonpoint source management efforts (Yoder 1995).

Bioassessment of Urban Watersheds

Ohio EPA uses biological criteria via a bioassessment approach in the designation and assessment of rivers and streams. Biological criteria are the principal tool for determining impairment of designated aquatic life uses and bioassessments play a central role in the Ohio Nonpoint Source Assessment (Ohio EPA 1990; 1991), the biennial Ohio Water Resource Inventory (305b report; Ohio EPA 1997), and watershed-specific assessments of which Ohio EPA completes from 6-12 each year. Biological criteria represent a measurable goal against which the effectiveness of pollution control and other water quality management efforts can be judged. However, biological assessments must be accompanied by appropriate chemical/physical measures, land use characterization, and source information necessary to establish linkages between stressors and the biological responses.

Methods And Analyses

For bioassessments to achieve their maximum effective use in the assessment of urban streams, a watershed design to sampling and analysis should be employed. A recent example is the Cuyahoga River basin in northeastern Ohio and small, wadeable streams of the Columbus metropolitan area (Franklin County) in central Ohio. The former represents historically and extensively urbanized streams including a mix of residential, commercial, and industrial land use, streams draining recent and rapid suburban development, and larger streams which are dominated by point source effluents, principally treated municipal sewage. The latter case includes small watersheds affected mostly by residential urban land use with a wide range of intensity from older areas to recent and rapidly developed suburban areas.

Biological and Water Quality Assessments

Fish and macroinvertebrates were sampled respectively, at 82 and 48 locations, in the Cuyahoga River basin in 1996, and an additional 32 locations were sampled for macroinvertebrates in 1991. Water samples were collected up to six times at 40 macroinvertebrate sampling locations and 63 fish sampling locations, and included standard field parameters (D.O., temperature, pH, conductivity), nutrient series (N and P), demand parameters (suspended solids, BOD, COD), and selected heavy metals. Drainage areas at Cuyahoga River basin stream sites ranged from approximately 2 to 700 mi^2. Fish communities only were sampled in the Columbus area, at 80 stream locations with drainage areas at all sites less than 35 mi^2. No water chemistry samples were collected. Macroinvertebrate community performance was evaluated using the Invertebrate Community Index (ICI; DeShon, 1995). The ICI is a multimetric index comprising ten attributes of community structure and composition. The individual metrics were scored against expectations derived from least-impacted reference sites (Ohio EPA 1987b, 1989a; DeShon 1995; Yoder and Rankin 1995). Fish communities were sampled using generator-powered, pulsed D.C. electrofishing units and a standardized methodology (Ohio EPA 1987b, 1989b). Fish community attributes were collectively measured with the Index of Biotic Integrity (IBI; Karr 1981; Karr et al., 1986) modified for Ohio streams and rivers (Yoder and Rankin 1995; Ohio EPA 1987b). Habitat was assessed at all fish sampling locations using the Qualitative Habitat Evaluation Index (QHEI; Rankin 1989, 1995). The QHEI is a qualitative, visual assessment of the functional aspects of stream macrohabitats (e.g., amount and type of cover, substrate quality and condition, riparian quality and width, siltation, channel morphology, etc.).

Two indicators of urbanization were developed for the Cuyahoga River basin, housing density and urban land use cover. Housing density by Census Block Group was obtained from the 1990 Census of Population (U.S. Bureau of Census,1990). Urban land use cover was derived from Landsat Thematic Mapper satellite imagery of land cover classification (September 1994) provided by the Ohio Department of Natural Resources. The number of housing units per hectare was calculated for the subwatershed upstream from each fish and macroinvertebrate sampling point to the boundary of the watershed. The percent urban land use for subwatersheds upstream from the fish sampling locations only were similarly calculated for both the Cuyahoga Basin and Columbus area study areas.

Statistical Analyses

IBI scores were regressed against chemical water quality parameters, an index of habitat quality (QHEI), and housing density. ICI scores were regressed against chemical water quality parameters and housing density. Water quality parameters were expressed as the average concentrations of phosphorus, dissolved oxygen (D.O.), nitrate+nitrite-nitrogen, ammonia-nitrogen, arsenic, lead, and cadmium (macroinvertebrates only) based on grab samples collected 6-8 times during June-October. Lead was highly intercorrelated with zinc, copper and chromium. Arsenic and cadmium were intercorrelated at fish sampling locations. Transformations used to correct departures from normality are provided in Table 1.

The relationship between different levels of urbanization, as indicated by housing density or percent urban land use (IBI only), and performance of the IBI, ICI, and selected metrics was further quantified using an analysis of variance model where quartile distributions of housing density and percent urban land use (e.g., 1st quartile ≤

Table 1. Parameter Estimates from the Regression of IBI on Water Quality Variables, Habitat Quality (QHEI) and Housing Density, and ICI on Selected Water Quality Variables and Housing Density.

Index of Biotic Integrity (IBI)

N: 63 | Multiple R: 0.606 | Squared multiple R: 0.368 | Adjusted R^2: 0.274

Effect	Coefficient	Std Error	t	P(2 Tail)	Adjusted R^2
Constant	23.318	11.019	2.116	0.039	
Log_{10}(Ar)	5.123	9.740	0.526	0.601	-0.011
Dissolved Oxygen	0.549	0.852	0.644	0.522	0.006
Log_{10}(Pb)	3.997	5.923	0.675	0.503	0.022
$1/NH_3$	-0.098	0.107	-0.916	0.364	-0.011
QHEI	0.091	0.095	0.952	0.346	0.071
Log_{10}(TP)	-7.876	4.781	-1.647	0.105	0.048
$Log_{10}(NO_x)$	-4.484	2.053	-2.184	0.033	0.063
(House/Hectare)	-7.171	1.769	-4.053	0.000	0.274

25th percentile of housing density, etc.) were used as factor levels. Metrics of the ICI that were used as dependent variables included the number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa, the percent composition of mayflies, other dipterans/non-insects, and tolerant taxa. IBI metrics used included the percent composition of omnivores, tolerant fishes, sensitive fishes, and insectivores. IBI scores and metrics from a subset of samples in the Cuyahoga Basin with drainage areas less than 100 mi^2 were also analyzed according to percent urban land use in a similar manner to examine for potential differences due to stream and watershed size. Because sample sizes varied widely in the subsets, multiple comparisons were made using Sheffé's procedure (Neter et al., 1991). An analysis of covariance model was constructed for Columbus area streams using quartiles of percent urban land use as factor levels, QHEI as a covariate, and IBI scores, percent composition of tolerant fishes, insectivores, and omnivores, the number of darter and sculpin species, and number of sensitive species as dependent variables. Multiple comparisons were made using Tukey's procedure (Neter et al., 1991).

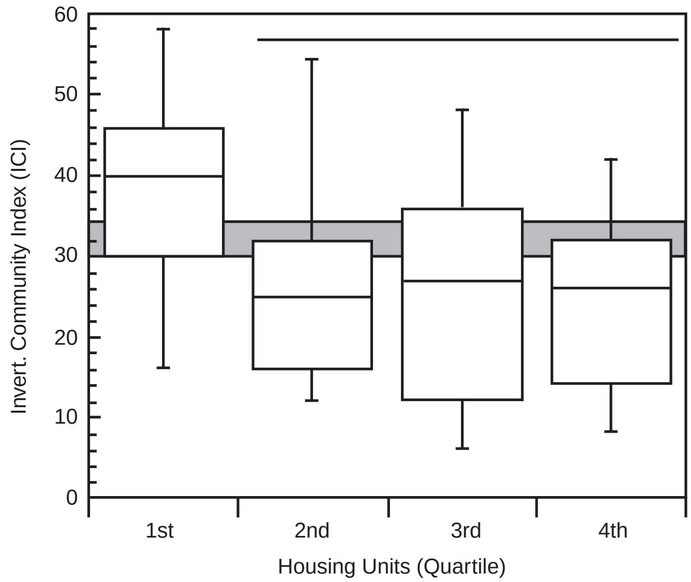
Because Cuyahoga River basin streams are subject to a variety of multiple stressors, fish sampling sites were qualitatively classified by predominant impact type and regressed against percent urban land use cover (log_{10} transformed) as a comparison to the results derived by using housing density and to determine the influence of impact type on the regression function. Impact types were defined as least impacted, estate (i.e*.,* subwatersheds with large lot-size residential homes or green space provided by parks), sites reflecting gross instream habitat alterations (i.e*.,* channel modifications or impoundment), sites impacted directly by discharges from combined sewer overflows (CSOs), sites impacted by wastewater treatment plant discharges alone and with CSOs, sites with evidence of impacts by legacy pollutants, or urbanization only. Regression coefficients from a subset of least-impacted, estate, and urban-only sites with drainage areas less than 100 mi^2 were compared to the same subset of sites for all drainage areas. Results of an ANOVA model using quartile distribution of percent land use as a factor level effect and IBI scores as independent variables were compared to those derived from the housing density model. Housing density, as an indicator of the degree of urbanization, was further evaluated by comparison with percent urban land use.

Housing Density and Biological Performance

When paired with chemical water quality data, housing density explained approximately 27% and 59% of the variation in IBI and ICI scores in the Cuyahoga River basin (Table 1). Of the water quality variables tested, only nitrate+nitrite-nitrogen and ammonia-nitrogen explained a small, but significant proportion of the variation in IBI and ICI scores (≈3% and 1%, respectively). For all IBI and ICI scores, housing density accounted for 31% and 23% of the variation in scores. Multiple comparisons of factor levels based on quartile distribution of housing density identified a threshold level of urbanization, coinciding with 2.53 housing units per hectare, beyond which IBI or ICI scores will increasingly fail to attain the biological criteria for the warmwater habitat use designation (Figure 1).

Shifts within the macroinvertebrate community were also associated with a threshold level of urbanization (Figure 2). The number of EPT taxa were significantly higher at the lowest levels of urbanization. Conversely, the percent composition of pollution tolerant taxa collected from the artificial substrate samplers increased sharply at sites exceeding the twenty-fifth percentile of housing density. Similarly, the percent composition of other dipterans and non-insects increased with increasing urbanization. The percent composition of mayflies found on the artificial substrates did not change with increasing level of urbanization (Figure 2).

Shifts in the compositional metrics of the fish community were associated with the degree of urbanization in the Cuyahoga River basin (Table 2) and included an increase in the relative abundance of tolerant and omnivorous fish. The relative abundance of omnivorous fishes, however, tended to be highest at intermediate levels of urbanization, but differences were not statistically significant for the subset of streams with drainage areas less than 100 mi^2. Insectivorous fishes were least abundant when housing density exceeded the seventy-fifth percentile threshold.



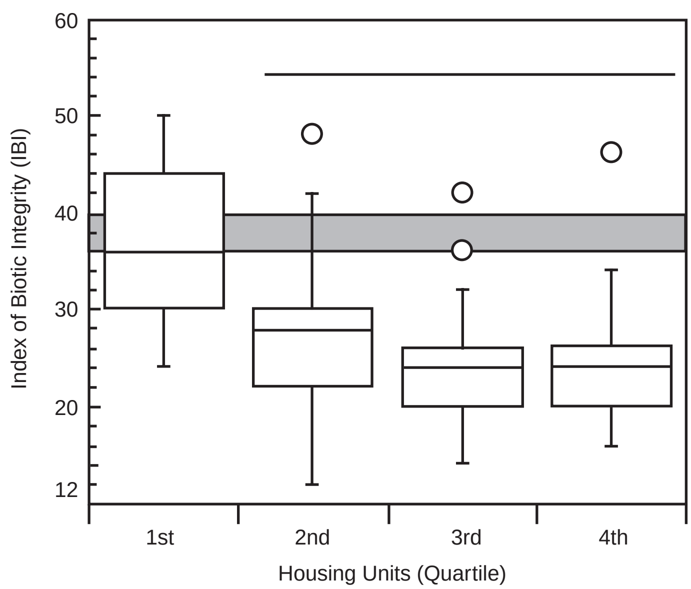


Figure 1. Distributions of Index of Biotic Integrity (IBI; lower) and Invertebrate Community Index (ICI; upper) scores from the Cuyahoga River basin plotted by quartiles of housing density upstream from sampling locations. The level of urbanization is given by quartiles of housing density per hectare of the subwatershed upstream from sampling locations. Horizontal lines spanning adjacent box plots indicate similar means. Levels of housing density per hectare corresponding to the 25th, 50th and 75th percentile are 2.53, 4.45 and 7.26 units/ha, respectively. The shaded areas indicate the applicable biological criterion and the range of insignificant departure.

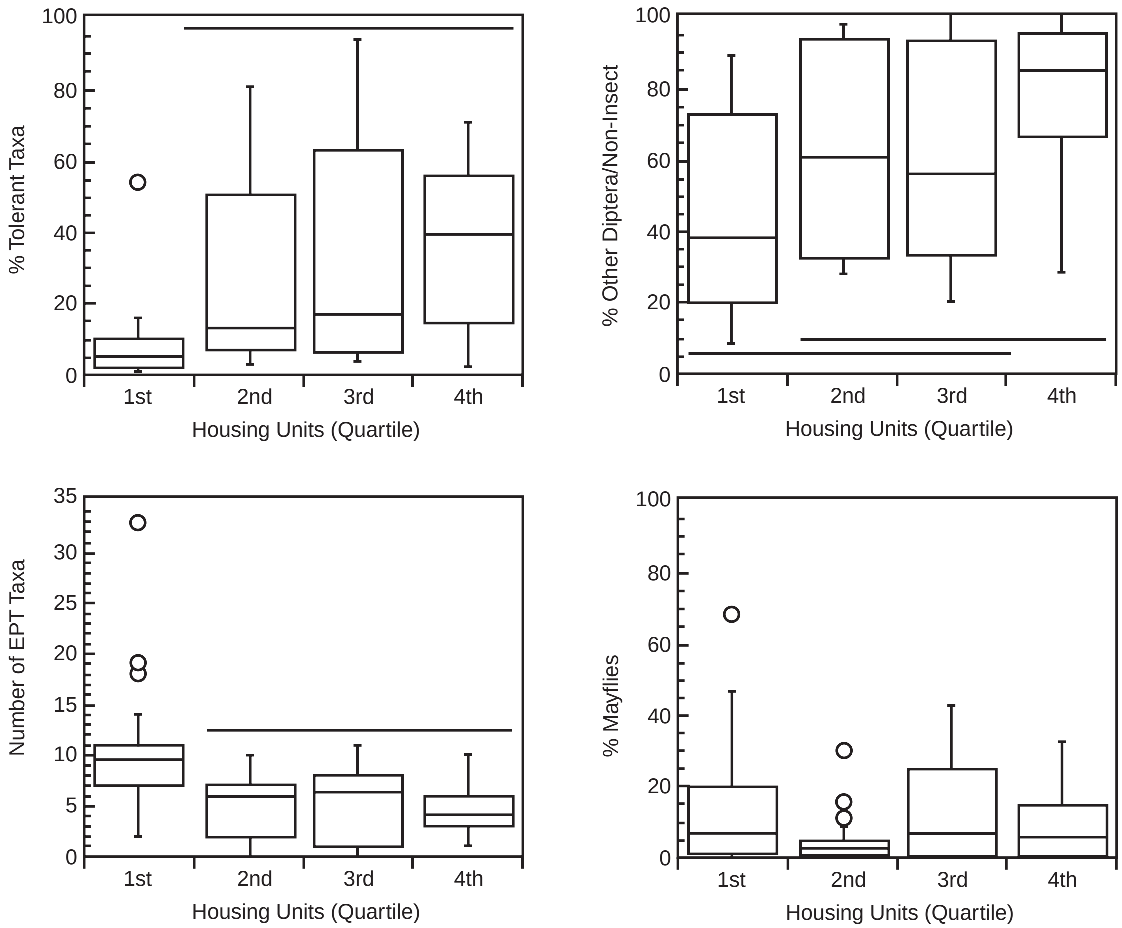


Figure 2. Performance of four Invertebrate Community Index (ICI) metrics in relation to housing density for the Cuyahoga River basin. The level of urbanization is given by quartiles of housing density per hectare of the subwatershed upstream from sampling locations. Horizontal lines spanning adjacent box plots indicate similar means. Levels of housing density per hectare corresponding to the 25th, 50th and 75th percentile are 2.53, 4.45 and 7.26 units/ha, respectively.

Urban Land Use and Biological Performance

The percentage of urban land use cover explained 26.7% of the variation in IBI scores in the Cuyahoga River basin, similar to that explained by housing density. When classified by quartile level of percent urban land use cover, the mean of IBI scores in the first quartile was significantly higher than those in the third or fourth quartile (Figure 3). However, classification by percent urban land use cover showed a more continuous decrease in mean IBI scores with an increasing level of urbanization than did housing density. Multiple comparisons of component IBI metrics classified by level of urban land use cover showed similar average responses to increasing urbanization as did classification by housing density (Table 2). However, intraquartile variation of the metric responses was greater among urban land use cover than for housing density, leading to fewer significant differences between means and reflecting the more continuous decrease in mean IBI response with respect to percent urban land use cover.

Significant differences in mean IBI scores between the levels of urban land use were also found for Columbus area streams (Figure 3). Mean IBI scores from streams with less than 3% urban land use were significantly higher than those with greater than 33% urban land use (Figure 3). Shifts in the composition of the fish community associated with increasing percent urbanization included the loss of darters, sculpins, and other pollution and habitat sensitive species, decreased abundance of insectivores, and an increase in the proportion of tolerant fishes (Table 3).

Discussion

Threshold levels of urbanization beyond which biological communities are likely to be impaired have previously been identified in the range of 8% to 20% impervious cover within a watershed (Schuler 1994). The threshold levels in our study of approximately 8% and 33% urban land use cover for the Cuyahoga River basin and Columbus area streams, as identified by analysis of variance, is in general agreement with the studies reviewed by Schuler (1994).

Table 2. Factor Level Means and Sheffe´ Groupings for Selected Fish Community IBI Metrics Sampled in the Cuyahoga River basin in Relation to Urban Land Use Indicators. Means Sharing a Common Letter are Not Significantly Different. The Asterisks Denote where Significant Differences Between Groups were Not Detected in Multiple Comparisons for the Percent Tolerant Group from all Sites, and for the Number of Sensitive Species in Streams Less than 100 Mi^2, The Overall F Tests Indicated a Significant ($P < 0.05$) Linear Relationship.

Urban Indicator (Quartile)	N	Number of Sensitive Species		Percent as Insectivores		Percent as Tolerant		Percent as Omnivores	
All sites - Housing Units per Hectare									
1st	22	A	3.0	A	49.9	A	31.9	A	15.1
2nd	21	AB	2.1	A	39.2	AB	38.2	B	28.3
3rd	19	CB	1.4	A	27.4	AB	48.1	B	48.4
4th	21	C	0.4		10.5	B	71.4	AB	22.1
All sites - Percent Urban Land Use									
1st	22	A	2.5	A	49.5	A*	35.9	A	18.7
2nd	21	A	2.2	A	41.4	A	40.4	A	27.7
3rd	19	AB	1.4	B	18.6	A	54.2	A	38.7
4th	21	B	0.7	B	14.6	A	58.2	A	31.0
Drainage Area < 100 mi^2 - Percent Urban Land Use									
1st	12	A*	2.5	A	44.8	A	46.5	A	22.7
2nd	11	A	2.0	A	40.8	A	44.3	A	20.4
3rd	9	A	0.8	B	13.2	A	66.1	A	11.5
4th	17	A	0.6	B	10.5	A	69.7	A	24.9

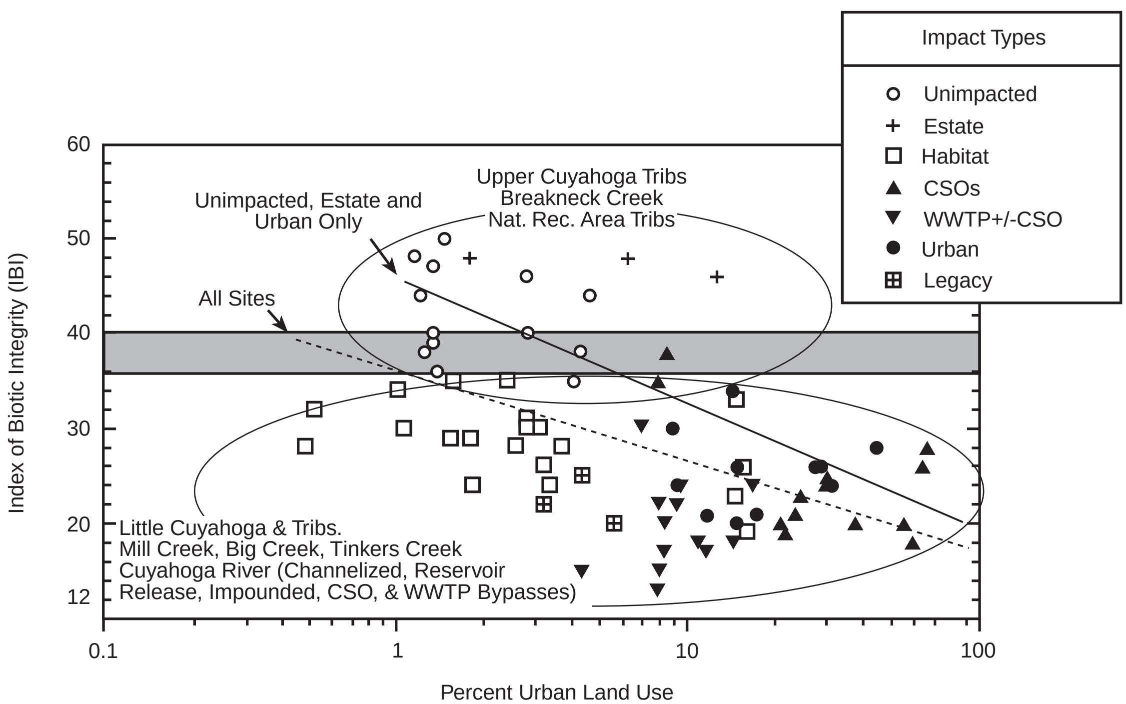


Figure 3. Distribution of Index of Biotic Integrity (IBI) values plotted by quartiles of percent urban land use cover upstream from sampling locations for all sites in the Cuyahoga River basin, Cuyahoga basin sites with drainage areas less than 100 mi^2, and Columbus area streams. The shaded areas indicate the applicable biological criterion and the range of insignificant departure.

Table 3. Factor Level Means and Tukey Groupings for Selected Components of Fish Communities Sampled in Columbus Area Streams. Means Sharing a Common Letter are not Significantly Different. Samples Sizes in Ascending Order by Quartile are 20, 18, 20 and 20; Two Cases in the Second Quartile had Missing Values Due to No Fish.

Percent Urban by Quartile	Number of Sensitive Species		Number of Darters/Sculpins		Percent as Insectivores		Percent as Tolerant		Percent as Omnivores	
1st	A	3.3	A	3.1	A	40.8	A	54.6	A	13.0
2nd	A	3.8	AB	2.2	AB	32.0	A	56.3	A	13.9
3rd	B	0.9	CB	1.1	B	17.0	B	82.7	A	10.5
4th	B	0.6	C	0.6	B	19.7	B	78.3	A	5.1

However, the threshold level identified by regression for the Cuyahoga River basin was influenced by the presence of other stressors (e.g., CSOs, point sources, legacy pollutants). The elimination of those sites impacted by other stressors from the regression resulted in an increased threshold of urbanization (Figure 4). Although other stressors acted as covariates in a sense, these were not amenable to an analysis of covariance because each occurred in relatively discrete groupings along the continuum of increasing urbanization. Analysis of variance was better able to identify a threshold level by contrasting discrete ranges (i.e., quartiles) along the entire range of increasing urbanization (Figure 3).

Similar patterns in the effect of increasing urbanization on biological communities were evident for both the Cuyahoga River basin and Columbus area streams. Detectible differences in the number of sensitive fish species in Columbus area streams occurred at lower levels of urbanization than did IBI scores, illustrating the role of sensitive species as sentinels of urban effects. Sensitive fishes are rare in the Cuyahoga River basin as a whole due to historic, complex, and widespread anthropogenic stressors, yielding less response and higher variation associated with interquartile means compared to the Columbus area streams. However, the number of EPT taxa, a sensitive macroinvertebrate guild, similarly acted as sentinels of urbanization given that EPT abundance was significantly reduced at relatively low levels of urbanization. The abundance of mayflies, showing little correlation with the level of urbanization, did not respond in a manner similar to the number of EPT taxa. While this may reflect the difference in collection technique as percent mayflies are based on the data from artificial substrates, whereas EPT taxa are based on data collected from natural substrates, it may also be due to differing sensitivities within the EPT guild. This result, in combination with the response of the fish community, implies that substrate degradation is a major factor which limits aquatic communities at relatively low levels of urbanization.

The relative abundance of omnivores tended to be highest at intermediate levels of urbanization when all sites in the Cuyahoga Basin were included. This response was due in part to enrichment by wastewater treatment plant discharges and CSOs discharging to the Cuyahoga River mainstem. No differences were detected for the subset of streams with drainage areas less than 100 mi^2, nor in the Columbus area streams. However, the relative abundance of insectivores was negatively correlated with increasing urbanization in both study areas, suggesting a disruption within the aquatic food web. Conversely, the proportion of tolerant fishes was positively correlated with increasing urbanization. The high proportion of tolerant fishes at the highest levels of urbanization is indicative of both degraded habitat and water quality, specifically toxicity and organic enrichment. Collectively, these changes in biological communities suggest a continuous negative response to increasing urbanization starting with the loss of sensitive fish and macroinvertebrate species at comparatively low levels of urban development (<5% urban land use) due to substrate degradation, disruption within the aquatic food web at intermediate levels of development, and a response to toxicity, organic enrichment, or both at higher levels of development (>15% urban land use).

Overlaying impact types with percent urban land use (Figure 4) demonstrates that the negative effects of urbanization and associated cofactors (e.g., imperviousness, polluted runoff, altered hydrology) may be partially offset by beneficial land use practices. Biological performance at sites impacted by estate-type residential developments remained comparatively intact and attained the ecoregion biocriteria even at relatively high levels of urbanization (up to 15%). The best performing sites within those watersheds also had relatively intact stream habitat and well-vegetated, wider riparian buffers. Conversely, sites with increasingly modified habitats performed poorly and failed to attain the biocriteria regardless of the degree of urbanization. The most degraded sites were associated with either poorly treated sewage, CSOs, and/or a high degree of urbanization. These findings agree with those of Steedman (1988) who demonstrated a co-relationship between riparian zone quality and land use in terms of how each affected the fish communities of Toronto area streams. Horner et al. (1997) found the steepest rates of decline in biological functioning (in terms of the B-IBI; Kerans and Karr 1992) to occur with increases in impervious cover of as little as 1-6% in streams flowing into Puget Sound, Washington. Exceptions occurred where urban land use was mitigated by extensive riparian protection or other management interventions, but these factors ceased to be effective above 45% as impervious land cover.

Unlike the Cuyahoga River basin, the Columbus area streams were not subject to extensive CSO impacts and

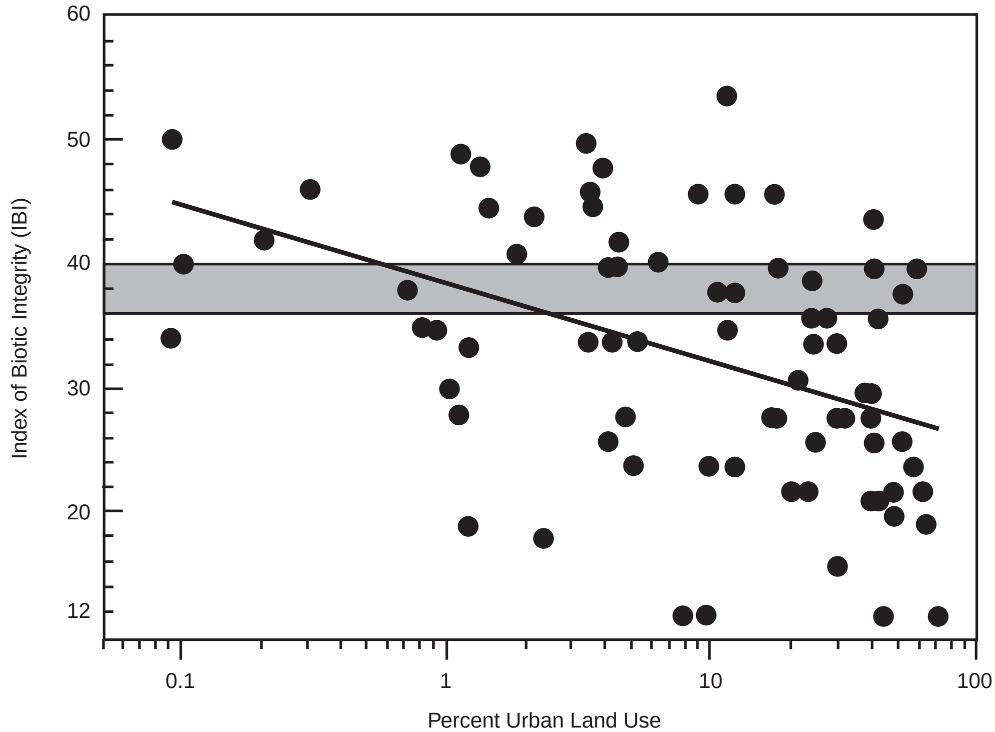


Figure 4. Index of Biotic Integrity (IBI) scores from sites sampled in the Cuyahoga River basin plotted by stressor group (symbols) agains percent of urban landuse for sites draining less than 100 mi². The fitted regression lines are for all points and those lacking stressors other than urbanization. The shaded areas indicate the applicable biological criterion and the range of insignificant departure.

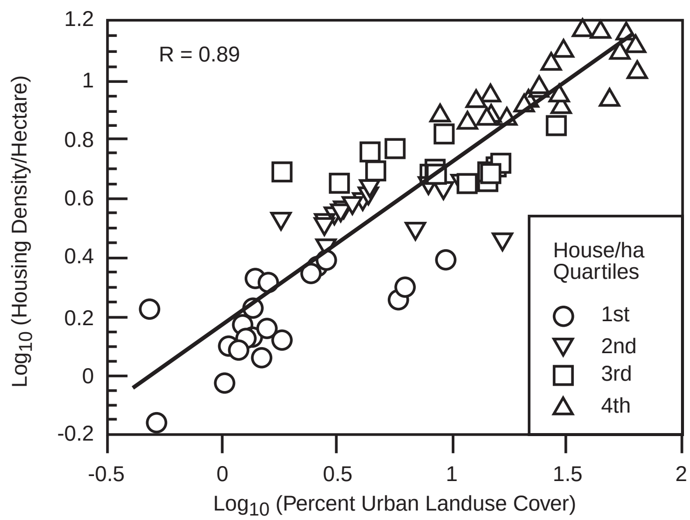
industrial legacy pollutants were virtually absent. Consequently, the threshold level of urbanization precluding attainment of the biological criteria was higher for the Columbus area streams (Figure 5), results which are analogous to that for sites influenced by the estate impact type in the Cuyahoga River basin. In fact there were a few sites with urban land use as high as 50% which fully attained the ecoregional biocriterion. This suggests that the type of urban development strongly influences the attainability of aquatic life uses within a watershed. Furthermore, factors such as impermeability and urbanization alone do not automatically disqualify streams from meeting designated uses based on biological criteria.

Although housing density and percent urban land use demonstrated a strong linear relationship (Figure 6), each urban indicator showed somewhat differing results. The percent of urban land use indicator, which is a more precise measure of urbanization and imperviousness, was negatively correlated with biological community performance. By comparison, the housing density indicator showed a discrete threshold between the lowest quartile and all others. The principal difference is that high-quality sites were more frequently associated with the second quartile of percent urban land use than for housing density, reflecting good IBI scores from relatively urbanized subwatersheds containing large residential lot sizes and more green space. Also, urban land use within successive quartiles of housing density apparently becomes increasingly mixed as inferred by increasing interquartile variation in percent urban land use (Figure 6). Higher levels of housing density coincided with increased industrial, commercial, and transportation related land uses. The difference in results by urban indicator underscores the importance of maintaining natural features within a watershed including instream habitat, vegetated riparian buffers of adequate width, and green space in addition to minimizing and controlling chemical impacts from wastewater treatment plants, CSOs, and other sources.

Implications for Use Attainability

Uses designated for specific water bodies are done so with the expectation that the criteria associated with the use are reasonably attainable. If CWA goal uses (e.g., warmwater habitat in Ohio) are found to be unattainable, lower uses may be established and assigned on a case-by-case basis. Federal water quality regulations (40CFR Part 131.10[g]) generally specify three criteria for setting designated uses below "fishable/swimmable" standards as follows: 1) imposition of the criteria for a higher use would result in widespread, adverse socioeconomic impacts; 2) the criteria are not attainable due to natural background conditions; or 3) the criteria are not attainable due to irretrievable, anthropogenic impacts.

Compliance with the aquatic life uses defined in the Ohio WQS are determined primarily by the biological criteria (OAC 3745-1-07) which are stratified according to designated use, ecoregion, and stream size. As such this repre-



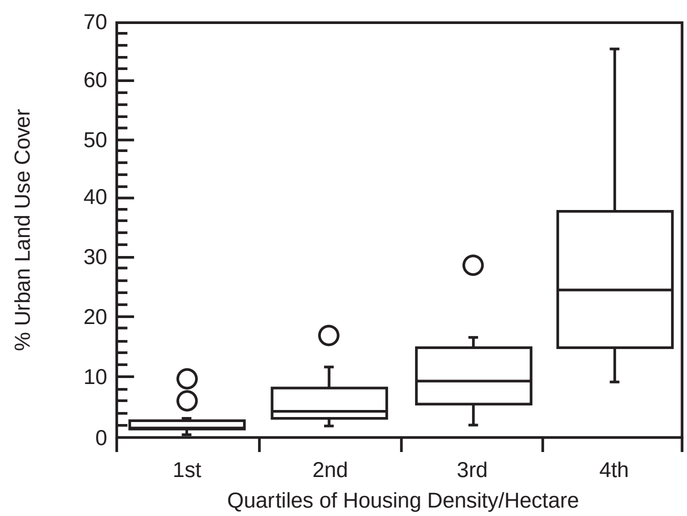


Figure 5. Index of Biotic Integrity (IBI) scores from sites sampled in Columbus area streams against percent of urban land use. The fitted regression lines are for all points and those lacking stressors other than urbanization. The shaded areas indicate the applicable biological criterion and the range of insignificant departure.

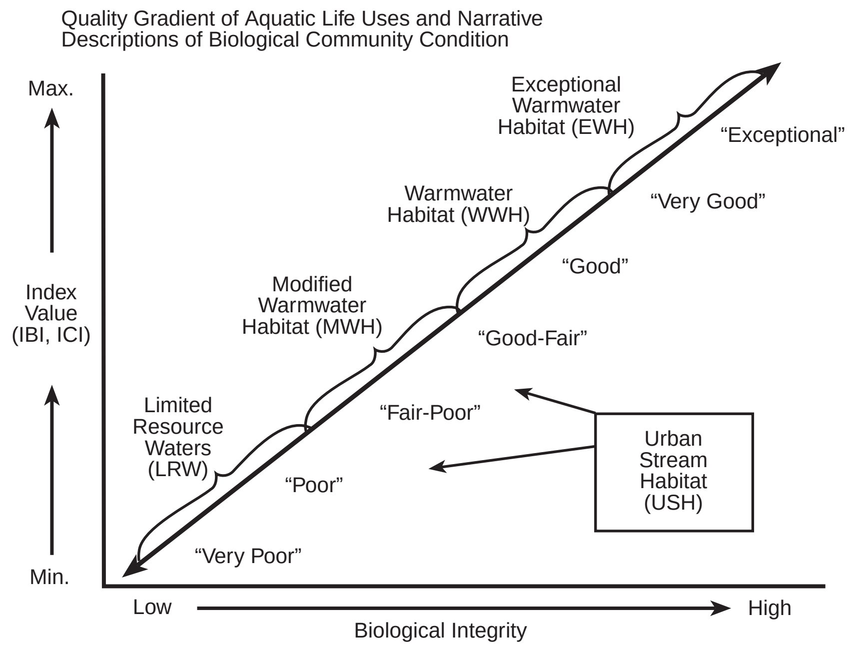


Figure 6. Relationship between housing density and percent of urban land use cover for subwatersheds upstream from fish sampling locations in the Cuyahoga River basin. The upper plot shows housing density as a function of percent urban landuse cover. The lower plot shows distributions of percent urban land use cover within quartile levels of housing density per hectare.

sents a stratified system of uses and criteria that occur along a gradient of biological integrity as expressed by the biological indices which comprise the numerical biological criteria (Figure 7). For most Ohio streams the "default" expectation is attainment of the warmwater habitat (WWH) use provided the physical habitat is relatively intact and no extensive alterations are evident. Obvious anthropogenic alterations to small urban streams such as culverting, relocation, bank and channel stabilization with artificial structures, and extensive channelization are relatively easy to identify and assess. In such cases, the Limited Resource Waters (LRW) use designation is assigned which means that the minimum level of protection (i.e., prevention of lethality) afforded by the Ohio WQS applies. The difficulty is with small urban streams that exhibit adequate habitat (as defined by the QHEI score), but which fail to attain the WWH biocriteria. The recent finding that no urban headwater stream sites in the Ohio EPA database attain the WWH biocriteria (Yoder and Rankin 1997) only serves to further the notion that the degree of watershed urbanization can preclude the WWH use regardless of the site-specific habitat quality.

Recently, the imperviousness of the watershed has been used as an indicator which is correlated with use attainability. If the frequently cited threshold of 25% impermeability is used, streams in watersheds with greater than this value would be unlikely to ever attain a beneficial use regardless of site and reach factors. The results of our study suggest that there is a threshold of watershed urbanization beyond which attainment of the WWH use is increasingly unlikely. However, this threshold is different among watersheds as evidenced by the results from the Cuyahoga Basin and Columbus area streams. Co-occurring factors such as pollutant loadings, watershed development history, chemical stressors, and watershed scale influences such as the quality of the riparian buffer and the mosaic of different types of land use also greatly influence the biological quality in the receiving streams.

While the development of indicators of watershed urbanization has merit from a management and decision-making standpoint, there are simply too many other factors, some of which are controllable and amenable to remediation, to use it as a sole determinant for aquatic life attainability. We suggest that the co-factors in addition to urban watershed indicators be better developed and tested using datasets from broader geographic areas and spanning the extremes of the urbanization gradient. One goal should be to develop, if appropriate, an urban stream habitat designation that would fit along the already existing hierarchy of aquatic life use designations in Ohio (Figure 7). We have indicated on Figure 7 where the biological criteria for this potential new designation might occur compared to the already existing hierarchy of aquatic life uses in the Ohio WQS. However, placing it on the existing quality gradient will require substantial calibration and validation with existing datasets. Having this use would satisfy the desire to afford streams with the maximum protection practicable, while recognizing the inherent limitations that urbanization imposes on stream quality.

In the meantime, simplistic regulatory and management approaches should be limited, particularly in those water-

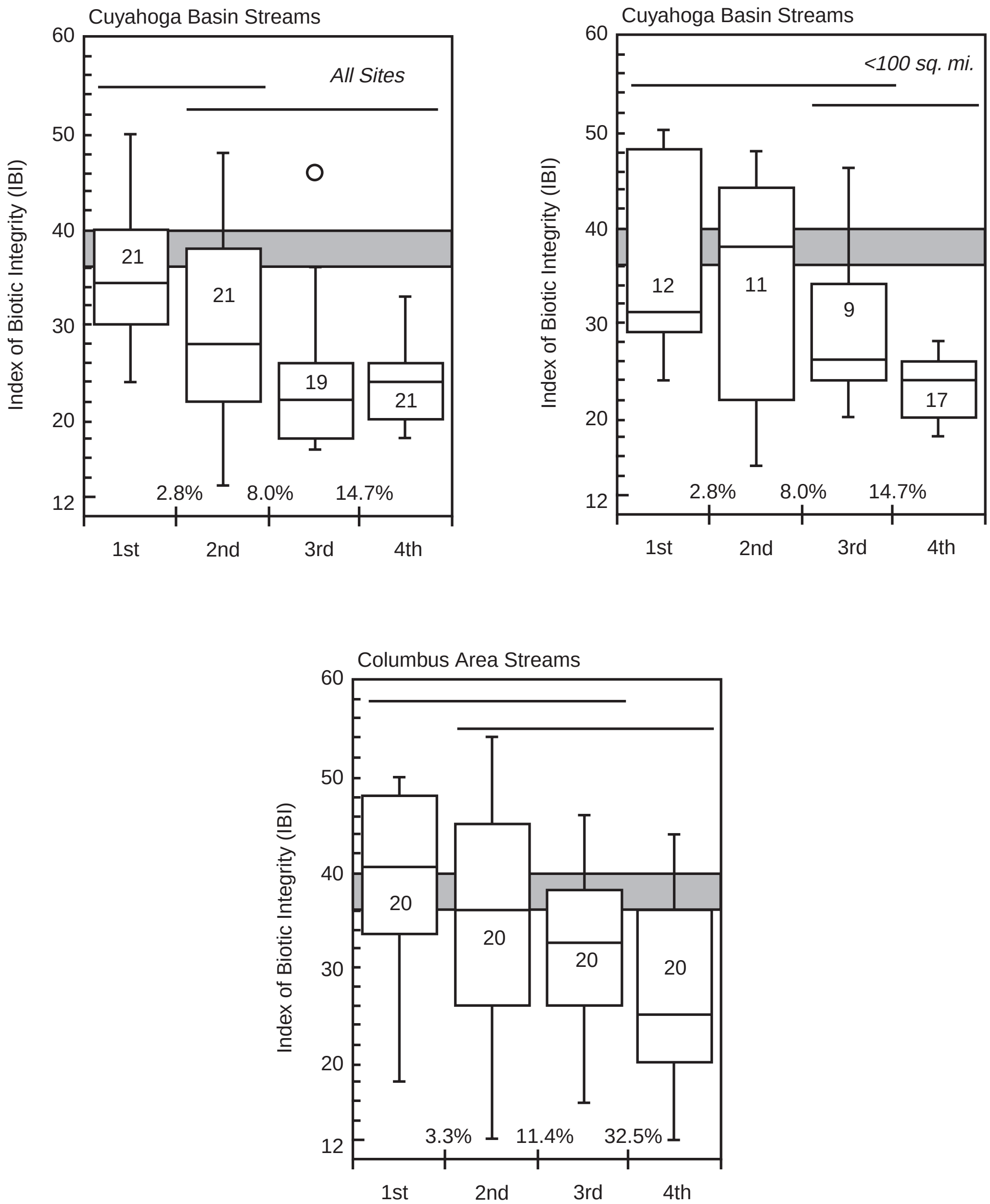


Figure 7. Index of Biotic Integrity (IBI) scores from sites sampled in the Cuyahoga River basin plotted by stressor group (symbols) against percent of urban land use for sites draining less than 100 mi^2. The fitted regression lines are for all points and those lacking stressors other than urbanization. The shaded areas indicate the applicable biological criterion and the range of insignificant departure.

sheds where uncertainty about the attainability of CWA goal uses (i.e., WWH and higher) exists. For example, initial approaches such as the nine minimum controls for CSOs seem reasonable. However, proceeding beyond these requirements with long-term control plans should be done cautiously and with the aid of sufficiently robust before-and-after biological and water quality assessments.

The results of our study also point out the benefits of a regular, sustained, and robust state monitoring and assessment effort (see also Yoder and Rankin 1998). Dealing with complex water quality management issues such as CSOs, stormwater, and TMDLs in urban watersheds would be difficult at best within the confines of the traditional administrative approach to water quality management. Steedman (1988) described multimetric biological indices like the IBI and ICI as being based on simple, definable ecological relationships which is quantitative as an ordinal, if not linear, measure and which responds in an intuitively correct manner to known environmental gradients. Further, when incorporated with mapping, monitoring, and modeling information, such an approach has been shown to be valuable in determining management and restoration requirements for warmwater streams (Steedman 1988; Bennet et al., 1993). The value added by a robust bioassessment and tiered use designation framework coupled with sufficiently detailed and accurate GIS information was amply demonstrated herein.

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Tampa Bay Environmental Monitoring Program

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Significant damage to, and loss of natural habitats in Tampa Bay can be traced to the uncontrolled development and pollution that started in the 1950s. Although great strides have been made over the last decade to reverse this trend, many agreed that a bay management and restoration plan, including monitoring programs that would evaluate bay conditions and progress, were needed.

The nomination and designation of the Tampa Bay National Estuary Program (TBNEP) in 1990, provided the platform to assist the community in developing a comprehensive plan to protect and restore the bay.

The process for developing the master plan includes the following components: identify and rank priority problems; assess bay conditions and needs; establish specific goals for the bay; develop management options; prepare the Comprehensive Conservation and Management Plan (CCMP); develop an implementing agreement among bay partners; implement the plan; and monitor progress (TBNEP 1996).

Methodologies for bay assessment, goal setting and development of comprehensive monitoring strategies are described. These methodologies could be useful to others interested in evaluating environmental protection and restoration schemes for natural resources.

Program Organization and Goal Setting

Since there already existed strong local and regional involvement in bay management, the TBNEP built on this commitment through the creation of its governing structure which consisted of the following committees: Policy, Management, Technical Advisory (TAC) and Community Advisory (CAC). From the Program's inception, the overall management goal was to protect and enhance the bay's natural resources. In support of this goal, the committees were required to characterize the natural systems of the bay and the impacts to these systems and define and implement actions to address those impacts. A Management Conference, with participation from all committees and stakeholders, was convened to identify priority bay issues. The following priority problems were identified by the Policy Committee in March 1991(TBNEP 1996):

- Water quality deterioration/eutrophication
- Reduction/alteration of living resources
- Lack of community awareness
- Increased user conflicts and impacts from various recreational activities, industrial and navigation needs, and urban development
- Lack of agency coordination and response
- Lack of circulation and flushing
- Hazardous/toxic contamination

Traditionally, monitoring and evaluating water quality conditions within a watershed are used to measure watershed health and productivity. Vigorous bay monitoring and management activities were being conducted by the time the TBNEP began in 1991; however, many of these activities focused on individual components and/or processes of the bay (Greening 1998). It was necessary to organize the information, coordinate bay managers' and stakeholders' participation and evaluate how these individual activities could be integrated to establish bay ecosystem management.

Quantifiable Restoration and Protection Goals

In keeping with the overall goal of protecting and restoring the bay's natural resources, the TAC worked to define species or biological communities which could be used as "indicators" of functioning bay ecosystems. The significant loss of submerged aquatic vegetative ("seagrass") habitat stood out as the premier concern of bay managers, scientists and concerned public. This habitat is crucial for many invertebrates and fish and provides for sediment stabilization (Busby and Virstein 1993). If quantifiable seagrass restoration goals and management strategies could be developed and implemented, it would be feasible to develop similar procedures for restoring other targeted habitats and natural resources.

Quantitative targets for the restoration and protection of seagrass habitat, as well as emergent habitats, were approved at a Management Conference in 1993. The approach to habitat restoration and protection was as follows (Janicki et al., 1994):

1. Map the historic living resource distribution during a benchmark time period.
2. Map the existing distribution of these living resources.
3. Overlay the historical and existing distributions to define potential restoration and protection targets.
4. Subtract physically altered (non-restorable) areas to identify restoration targets.

Seagrass Restoration and Protection Goals

Utilizing the approach described above, it was determined that the benchmark for establishing seagrass protection and restoration goals would be the period circa 1950. This era was chosen because the area was beginning to experience explosive growth and the major development alterations were not yet complete. Additionally, comparable habitat data were not available before 1950 (NUS Corp. 1986).

Using aerial photography coupled with the Arc/Info GIS system, it was determined that the extent of seagrass coverage in 1950 (not including areas that were irrevocably altered by 1990) was estimated to be 40,400 acres (NUS Corp. 1986). In 1990, Ries (1993) estimated the seagrass habitat coverage to be approximately 25,200 acres. Having already factored the physical losses due to dredge and fill activities, the remaining losses were most likely caused by degraded water quality conditions (Janicki et al., 1994). Recent investigations suggest that the loss of seagrass meadows can be attributed to lack of sufficient sunlight because of attenuation by excess phytoplankton, suspended solids and epiphytic algal growth (Morris and Tomasko 1993; Tomasko 1993; and Stevenson et al., 1993). Excessive algal concentrations or eutrophic conditions are predominantly caused by excessive nutrient (e.g., nitrogen and phosphorous) loading.

Acreage goals for seagrass restoration and protection were developed by overlaying the 1950, 1990 and non-restorable acreage data sets. Seagrass areas observed in 1990 were designated as seagrass protection areas. All areas in which seagrasses were mapped in 1950, but which did not support seagrass in 1990 and were not classified as non-restorable, were identified as seagrass restoration areas (Greening 1998). Based on a review of the data sources, method evaluation and uncertainty in estimating the 1950 coverage, the Management Committee agreed to adopt a minimum seagrass restoration goal of 38,000 acres bay-wide. This goal includes protection of an existing 25,650 acres and restoration of 12,350 additional acres.

Development of Intermediate Targets

Assessing bay management success via living resource goals is considerably more difficult than using traditional water quality criteria because it takes much longer to realize results. It is not too difficult to evaluate annual water quality trend response to management actions. It has been demonstrated, however, that seagrass quality and quantity improvements may not be observed for decades after a management action is implemented (Johansson and Ries 1997). To ensure that correct management actions were being implemented and bay water quality improvements would lead to the achievement of the seagrass restoration and protection goal, it was necessary to establish intermediate targets so that more timely evaluations and management adjustments could be made if necessary.

In the Tampa Bay area it has been demonstrated that seagrass health and distribution are adversely affected by incident sunlight being attenuated within the water column by elevated suspended solids or phytoplankton concentrations (Lewis et al., 1985; Lewis et al., 1991). If seagrass does not receive adequate light, plant maintenance and reproduction are inhibited (Janicki et al., 1994).

For the purpose of determining the relationship between nutrient loadings to the bay and adequate water quality to support the seagrass restoration target, a two-pronged modeling approach was developed. The first was a series of empirical regression-based models to estimate external nutrient loadings consistent with the proposed seagrass enhancements (Janicki and Wade 1996), and the second was a WASP-based box model which provided a process-oriented examination of relationships between nutrient loadings, chlorophyll *a* concentration and light attenuation (Martin et al., 1996; Morrison et al., 1997).

Both the empirical and mechanistic models produced similar results, suggesting that acceptable nutrient management targets could be developed. The critical relationships that were established were external nitrogen (limiting nutrient) loads and resulting chlorophyll *a* concentrations; chlorophyll *a* concentrations and density of phytoplankton in the water column; and chlorophyll *a* concentrations and light levels at the deep edges of historic seagrass beds.

Since the estuary is about 1,031 km^2 (398 mi^2) with varying land uses, fresh water inflow, nutrient loadings and circulation patterns, it was decided that the best way to manage this system was to partition or segment according to similar conditions. The segmentation scheme defined by Lewis and Whitman (1985) was adopted to establish the official management subdivisions of the bay (Figure 1).

Following numerous scientific workshops, the TAC and Management Committee adopted chlorophyll *a* targets necessary to maintain water clarity needed for seagrass growth for each bay segment. The adopted segment-specific annual average chlorophyll *a* targets (8.5 *u*g/l for Old Tampa Bay; 12.3 *u*g/l for Hillsborough Bay; 7.4 *u*g/l for Middle Tampa Bay; and 4.6 *u*g/l for Lower Tampa Bay) will be used as indicators for evaluating water quality conditions necessary to meet long-term seagrass restoration and protection goals.

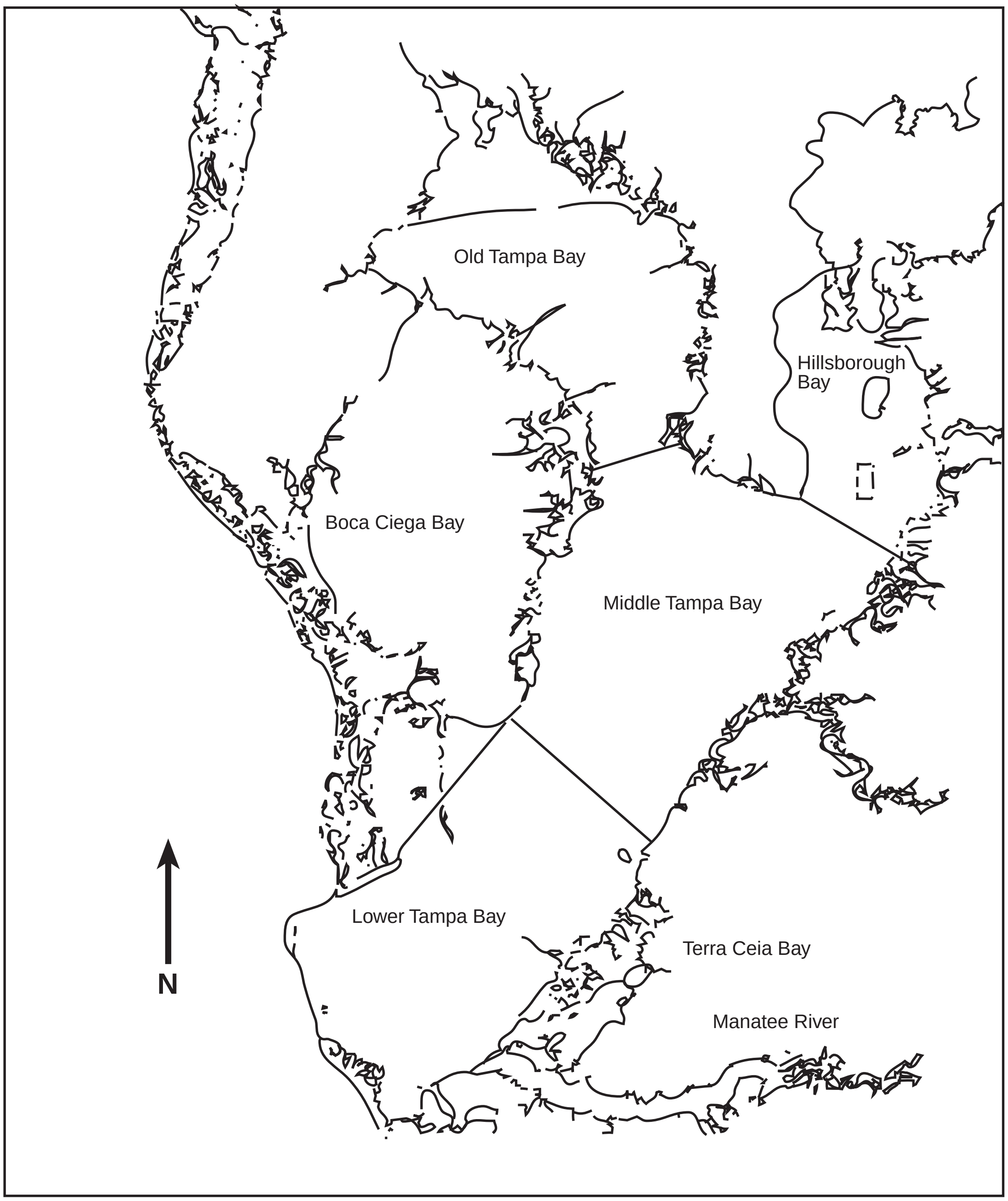

Figure 1. Tampa Bay, Florida segmentation scheme.

Nitrogen Management Strategy

Based on light conditions observed during a present day period (1992-1994), it was determined that water quality conditions were adequate to support the long-term seagrass restoration goals; therefore, a nitrogen loading "hold-the-line" strategy was adopted (Janicki and Wade 1996). This means that if the nitrogen loads observed during the period 1992-1994 remained constant into the future, it would be possible to achieve the seagrass restoration goal. However, it is estimated that by the year 2010, the watershed will experience a 20% increase in population and approximately a 7% increase in annual nitrogen loading (Zarbock et al., 1996).

In lieu of developing stringent future nitrogen load reduction allocations, local governments and agency partners in the TBNEP developed an unprecedented interlocal agreement (Memorandum of Understanding for the Federal agencies) pledging the development and implementation of action plans that will defer or reduce future nitrogen loadings, thereby maintaining the "hold-the-line" commitment.

Monitoring and Reporting

The process for developing monitoring strategies for this program was as unique as that used in developing the living resource goals. There were many monitoring activities ongoing when the TBNEP program was established, but these activities were localized and designed for specific needs.

The first task was to evaluate all of the different monitoring programs being conducted for Tampa Bay to determine whether they would meet the monitoring criteria for National Estuary Programs (USEPA 1991). Their criteria include: "measuring the effectiveness of management actions and programs implemented under the CCMP and providing essential information that can be used to redirect and refocus the management plan." Additionally, a 1992 monitoring workshop recommended four additional monitoring objectives (Versar 1992):

- To estimate the areal extent, and temporal trends in areal extent, of habitat conditions in Tampa Bay not meeting living resource requirements
- To assess the relative abundance and condition of fish populations of Tampa Bay over time
- To estimate the areal extent and quality of seagrass, mangroves, and coastal marshes in Tampa Bay over time and
- To estimate the areal extent and trends in areal extent of oligohaline habitat in Tampa Bay and its tributaries

To accomplish most of these monitoring objectives, it was decided that a probability-based sampling design be developed that would allow statistically valid, unbiased estimates of abundance and areal extent of key indicator species on a bay-segment and bay-wide basis. The chosen design was based on the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP) (Versar 1992). Since most of the existing monitoring activities were biased, fixed station designs, modifications to these programs were necessary.

In order to prepare and implement the new monitoring strategies, the local and regional agencies responsible for sample analyses and data reporting created a coalition known as the Florida West Coast Regional Ambient Monitoring Program ("RAMP"). RAMP participants meet regularly for the purpose of standardizing methodologies, evaluating quality assurance between laboratories, and coordinating field sampling strategies. These coordinated activities have 1) allowed the local agencies to develop expertise in areas other than general water quality monitoring (e.g., benthic and seagrass monitoring); 2) economized resources by linking bay areas and programs instead of creating overlap; and 3) allowed utilization of the existing EMAP probabilistic design to build monitoring programs required by other regulations (i.e., NPDES stormwater).

Another very important component of the monitoring strategy is reporting. The monitoring design described has both short- and long-term targets and goals. In order to provide bay resource managers timely information, the TBNEP, with assistance from state, regional and local scientists conducting monitoring and research, will prepare a biennial Tampa Bay Environmental Monitoring Report. The information provided in these reports is intended to provide decision makers timely access to information critical for successful restoration and protection of Tampa Bay's living resources.

Conclusions

The restoration and protection strategies designed for Tampa Bay by local, regional, state and federal participants epitomize coordinated ecosystem management. The development of resource-based targets, as defined by the environmental requirements of critical living resources, is difficult but essential for maintaining the health and productivity of critical habitats.

The real key to successes experienced in Tampa Bay is the concerted effort put forth by agency personnel, elected officials and concerned members of the public in dealing with difficult, complex issues and making critical management decisions. These accomplishments were possible because participants possessed dedication and commitment to restoring and protecting the living resources of Tampa Bay.

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Retrofit Opportunities for Urban Waters Using Soil Bioengineering

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Abstract

Soil bioengineering retrofits have been used to meet specific objectives, such as flood control, stormwater management, bank stabilization, aesthetics and habitat enhancement. In response to increasing environmental concerns, soil bioengineering systems using woody vegetation provide streambank protection in urban waters while maximizing ecological and water quality benefits in urban waters. Retrofit opportunities to restore incised and enlarged channels as well as those that have been relocated and/or straightened are discussed in this paper.

Case studies are presented to illustrate the use of this technology on several projects where geotechnical, hydrologic/hydraulic, and environmental objectives needed to be met. These included a flood control stream in an urban linear park in Charlotte, North Carolina; a relocated stream in Portland, Oregon; a flood control channel through a residential neighborhood in Houston, Texas; and an erosion and flood control stream restoration project in a residential neighborhood in Wilmington, North Carolina. Information is presented for evaluating alternative soil bioengineering streambank protection measures and selecting those that best achieve the desired goals

Introduction

Nonpoint source impacts on urban streams and adjacent lands have become increasingly damaging in many U.S. metropolitan areas, especially where streams have been straightened or relocated. Straightening of urban streams is often done to consolidate land for development, or to bypass lakes or public parklands. Uncontrolled stormwater runoff is also a significant contributor to the erosion of channel beds and banks of urban streams. The increased frequency and magnitude of these flows and their associated velocities results in stream damage and loss of valuable land.

Stream power is proportional to the product of discharge and slope. Both variables are increased when streams are straightened during development and subjected to increased discharges. Stormwater detention is a relatively recent concept, and most of the subdivisions and commercial sites developed during the 1960s and 1970s have no stormwater detention facilities (Nunnally and Sotir 1997).

Traditional land “repackaging” for convenience and short-term resale ignore not only the sediment transport that occurs during the construction phase and long-term channel stabilization problems; they also ignore water quality, aesthetic values and a host of environmental benefits including aquatic and terrestrial habitat. The opportunity of retrofit recovery through the use of soil bioengineering is discussed in this paper using case studies.

Geotechnical, Hydraulic and Hydrologic Benefits of Soil Bioengineering

Soil bioengineering methods offer a broad range of mechanical benefits when installed as retrofits to damaged urban stream systems (Table 1). Geotechnically, they offer immediate soil reinforcement up to a depth of 12 feet. The use of brushlayers with natural or synthetic geogrids, is especially useful where space is constrained, as these methods may be constructed on very steep slopes (1H to 1V; in some cases as steep as .25H to 1V). Installed vegetation offers many hydrologic values in that the embedded branches serve as horizontal drains converting parallel seepage flow to vertical flow, thus offering improved overall slope stability. Surface protection and reinforcement is further increased when live branches develop roots and top growth. The roots tend to consolidate the soil particles by reinforcing the soil mantle, reducing the possibility of slips and displacements. The top leaf and branch growth provides direct bank protection and reduces velocities while redirecting the flow away from the bank.

Environmental Benefits of Soil Bioengineering

Soil bioengineering offers a variety of environmentally sound retrofit opportunities for urban waterways. The main benefits of different methods have been summarized in Table 2. They may serve as a useful guide in the selection of specific vegetative methods. Soil bioengineering systems that use live siltation construction or create scour

Table 1. Soil Bioengineering System Geotechnical and Hydraulic Goals and Benefits

	Soil Bioengineering Methods							
Goals and Benefits	*Live Stakes	Live Fascine	Live Siltation Construc-tion	Branch-packing	Brush-mattress	Live Cribwalls	Vegetated Geogrid	Live Boom(s)
Geotechnical	fair	good to very good	n/a	good	n/a	excellent	excellent	n/a
Hydraulic	fair to good	good to very good	very good to excellent	excellent	very good	good to very good	good	fair to good

*After established (1 year).

Table 2. Environmental Benefits of Soil Bioengineering Streambank Restoration Systems

	Soil Bioengineering Methods						
Goals and Benefits	Vegetated Geogrid	Live Cribwall	Live Boom	Live Siltation Construction	Brush-mattress	Live Fascine	Live Stake
Shade and	excellent	excellent	very good	excellent	good to very good	good	fair to good
Create or Preserve Scour	good	very good	excellent	n/a	n/a	n/a	n/a
Riparian Habitat	fair to good	fair to good	n/a	very good to excellent	excellent	good to very good	fair to good
*Recreation	very good	very good	n/a	good to very good	good to very good	good	fair

*Visual perspective

holes using live booms (dikes composed of woody vegetation and soil) are excellent choices as part of a bank protection system where shade and overhanging cover or pool habitat is desirable (Sotir 1997c). The habitat for mammals and birds will improve over time in such areas for nesting, migration and cover.

In addition to the selection and orientation of methods, the choice of woody vegetation species in soil bioengineering systems can also have a significant effect on the habitat benefits. Various species of willow are the most commonly used woody plants because of their excellent rooting capabilities, good overhanging cover and shade, good nesting habitat for some species of birds, and some cover for mammals, other species offer better food sources for land animals. Soil bioengineering designs incorporate plants that provide the best habitat benefits for target species (Sotir 1997c).

Johnson Creek Relocation and Restoration

Johnson Creek is located in a highly urbanized area of Portland (Oregon), with land uses ranging from heavy industry to low-density residential. It is a third-order stream with a 100-year discharge at the project site of about 4,400 cfs. Flood control efforts during the 1930s enlarged, but did not straighten the stream. A survey of Johnson Creek revealed that with few exceptions, streambanks are stable, heavily vegetated, and provide excellent riparian habitat and overhanging cover for the stream.

The Oregon Department of Transportation (ODOT) proposed relocating a section of Johnson Creek in the Town of Milwaukie for bridge and highway construction (Figure 1). The relocated section would be about 20% shorter than the existing channel with a commensurate increase in gradient. The Johnson Creek Corridor Committee, created because of concerns over degraded water quality and aquatic habitat and with an interest in restoring an anadromous fishery, was worried about potential impacts of the stream relocation. The relocated stream reach is in a highly visible location, and the riprap channel proposed by ODOT would present a stark, sterile appearance and cause further loss of habitat and aesthetic value.

Robbin B. Sotir & Associates, Inc. (RBSA) was retained by ODOT to evaluate the proposed channel design for stability and for potential impacts to aquatic and riparian ecosystems and to modify the design as needed to address the concerns voiced by the Johnson Creek Corridor Committee. The review determined that the proposed trapezoidal channel cross-section shape and gradient were too uniform and that the floodplain berms were too high. RBSA

Figure 1. Johnson Creek after realignment activities.

recommended changes to the channel to improve stability, water quality, and habitat value (Sotir and Nunnally 1995). The channel cross-section was altered by lowering floodplain berms, incorporating a sub-channel to convey bank overflows, and constructing a low-flow channel to concentrate flows during the summer months. A pool-riffle sequence was created by widening the sub-channel and raising the invert by one foot in cross-over reaches and lowering the invert by one foot in outside meander sections.

Streambanks were riprapped to the ordinary high-water elevation in the outside bends. Banks above were soil bioengineered, using vegetated geogrids. Siltation constructions using live materials were installed on the lowest floodplain berm adjacent to the sub-channel to provide cover for waterfowl and overhanging cover for fish. The upper bank was protected with brushmattress.

The soil bioengineering systems were installed in the winter of 1993 and spring of 1994. During the early spring and before the plants had established growth, the site experienced a 1,750 cfs flood with mean velocities of 6-7-feet-per-second and maximum velocities estimated in excess of 10-feet-per-second. The soil bioengineering systems were secure, and by the end of the growing season they were providing excellent bank protection and habitat benefits (Figure 2).

Buffalo Bayou Bank Stabilization and Aesthetic Improvement

Buffalo Bayou upstream of Sheperd Drive is the only stream of any size in Houston (Texas) that has not been channelized for flood controls. The watershed of Buffalo Bayou is almost totally urbanized, and Addicks Reservoir was constructed upstream to alleviate flooding. The combination of natural flooding and operation of the flood gates at Addicks results in abrupt rise and fall of the water level in the bayou coupled with prolonged periods of both high- and low-water levels. These hydrologic conditions, combined with sandy and silty soils with little cohesion, have resulted in widespread erosion and large streambank failures.

Several soil bioengineering streambank protection projects were built on Buffalo Bayou between 1990 and 1995 (Nunnally and Sotir 1995; Gray and Sotir 1996). The 1990 sites survived one of the largest floods of record in 1992 without damage. The installation described here was constructed in 1992-93 following that flood.

The project site, located in an outside bend, is 280 feet long and its height varies from 25-35 feet. Due to the receding bank, over 20 feet of land had been lost (Figure 3). The bank recession was caused by a combination of mass slope failure and streambank erosion. The instability of the steepened slope was aggravated by the presence of fine sands and seepage of 200-2,000 gallons per day from the bank face. While the main goal for this project was to stabilize the bank and stop the erosion, the client was also interested in the restoration of the riparian zone, aesthetic improvements, and the ability to maintain a view to the Bayou.

To achieve long-term bank stabilization, a foundation of wrapped concrete rubble was installed in a 7-foot deep toe trench. A fill slope with a grade of 0.5 H:1V was reconstructed above this foundation. The fill was constructed in 2-foot lifts wrapped with a geogrid. Thick layers of brush long enough to extend from the undisturbed soil at the back

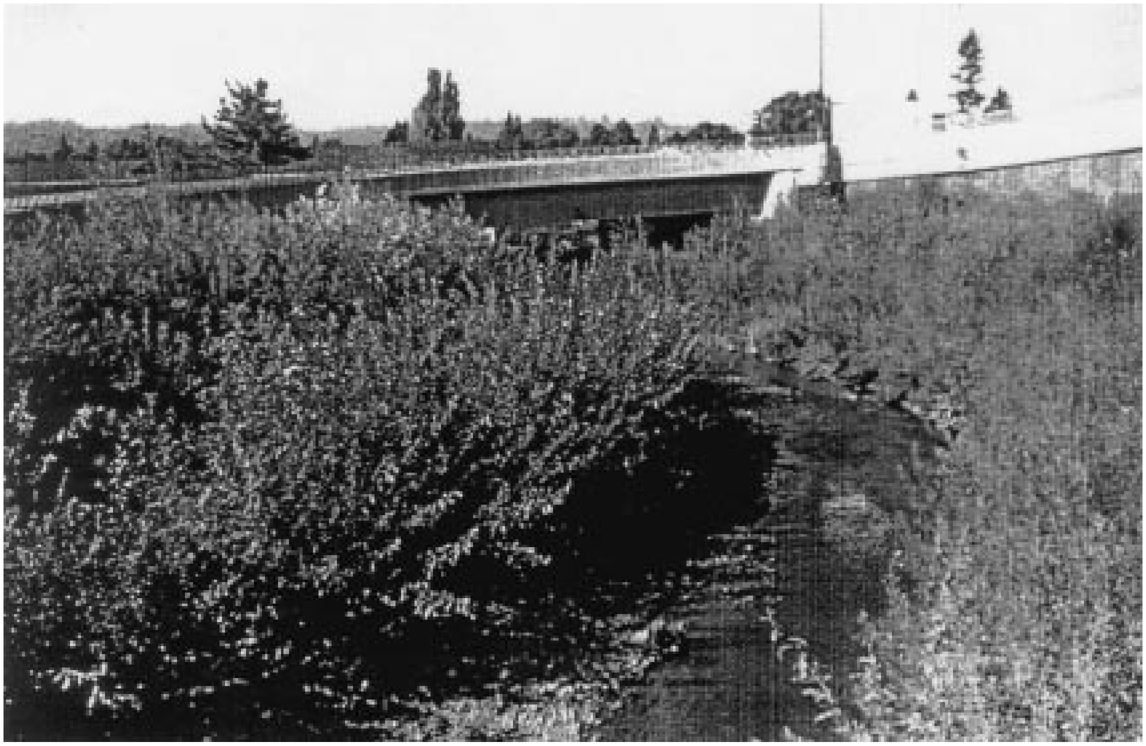

Figure 2. Johnson Creek four years after construction.

Figure 3. Buffalo Bayou erosional failure after a flood event.

of the bench and protrude several feet beyond the slope face were placed between each wrapped soil layer. The overall constructed height was 42 feet with the upper half being at 0.25H:1V. Because continued seepage would have substantially reduced the safety factor, it was necessary to install vertical chimney drain construction to conduct the water into a gravel trench drain that discharged into the bayou. Since construction, the site has experienced several floods and has remained stable; meanwhile, the installation is developing into a dense riparian buffer of native and naturalized species (Figure 4).

Little Sugar Creek Stabilization, Habitat Restoration & Flood Control

This 4,650-foot section of Little Sugar Creek is in the Huntington Farms Park area in the City of Charlotte (North Carolina). This linear park, located along the creek in a predominately residential neighborhood, is owned by the City of Charlotte and maintained by Mecklenburg County Storm Water Services.

Like most other streams in Charlotte, Little Sugar Creek was channelized to improve drainage in the early 1900s, and it has been dredged and snagged several times since then, often leaving the channel without any vegetative cover. The stream drains much of eastern and central Charlotte, and the watershed is highly urbanized. The frequent flooding and high peak discharges caused significant bank erosion and channel enlargement. The immediate area had also been used as a constructed landfill in the past. At several locations, bank erosion had uncovered construction debris burial sites containing tree trunks, waste construction materials, and miscellaneous organics (Figure 5).

An interdisciplinary team with expertise in hydrology, surveying, geotechnical and aquatic science, fluvial geomorphology, and soil bioengineering was assembled to develop a restoration and stabilization project. Goals included: bank stability, erosion protection, aquatic habitat enhancement, water quality and aesthetic improvement, community education and economic savings.

Design and cost information studies were initiated in April 1996. Erosional bank failures along the creek were evaluated, typed and matched with appropriate solutions. From this, final plan and specification documents were prepared. Initially, riprap rock was reduced or completely eliminated along the toe. This dramatically reduced the project costs. Soil bioengineering methods such as live fascines and brushmattress were employed in different configurations along the banks. Construction was completed in March 1997. Four months after installation, Little Sugar Creek experienced a flood that exceeded the 100-year event. The project sustained no damage. While this project is a very new installation, it has become well-vegetated, offering enhanced riparian benefits, overhanging cover, aesthetic improvements and bank stability (Figure 6). The instream habitat structures (current deflectors and rocks) have also been performing well, producing a variety of scour hole cover and resting areas for fish.

Figure 4. Buffalo Bayou five years after construction.

Figure 5. Little Sugar Creek erosion failures before construction.

Figure 6. Little Sugar Creek in the first growing season after construction.

Long Leaf Hills/Hewletts Creek Stabilization, Aesthetic and Habitat Enhancement

This stretch of Long Leaf Creek is located in a residential neighborhood in Wilmington (North Carolina) known as Long Leaf Hills Subdivision. Increased stormwater runoff due to urbanization of the watershed and frequent flooding in the lower section have caused significant bank erosion and channel enlargement. Bank seepage and uncontrolled overbank runoff also contributed to bank failure (Figure 7 and 8). The creek has been used as a dump site for organic garden debris which kills the bank vegetation and has worsened erosion. Public meetings focused community concern on existing conditions and spurred interest in stabilization and restoration based on ways that residents wanted to use and enjoy the creek in the future.

Kimley-Horn & Associates, Inc., the prime consultant, and Robbin B. Sotir & Associates, Inc. prepared six conceptual alternatives which included a simple intermediate action for cleanup and stabilization, grass, riprap rock and concrete liners, box convert, and soil bioengineering. Alternatives were matched against 11 critical issues (Table 3). Soil bioengineering was selected by the neighborhood as it fulfilled all the criteria. The project is currently in the final design stages. Construction is scheduled to start in the fall of 1998 and is expected to be completed by late winter of 1999. Monitoring will be performed after construction to evaluate the stabilization and restoration development of Long Leaf Hills/Hewletts Creek (Sotir 1997a).

Summary

Urban water restoration and stabilization projects involve multiple objectives. In addition to controlling erosion in a cost-effective manner, we are increasingly concerned with water quality, habitat, aesthetics, recreational use and other environmental objectives. Soil bioengineering designs that employ woody vegetation meet these environmental objectives better than other types of streambank protection, especially when integrated with other technology. The successful retrofit applications of soil bioengineering on urban waters discussed in this paper indicate that this approach to stabilization and restoration is successful.

Figure 7. Hills/Hewletts Creek/Long Leaf failure conditions

Figure 8. Long Leaf/Hills/Hewletts Creek failure conditions

Table 3. Long Leaf Hills/Hewletts Creek Alternatives and Critical Issues

Critical Issues	ALT. #1 Intermediate Action	ALT. #2 3:1 Side Slopes Grass Lining	ALT. #3 2:1 Side Slopes Riprap Rock	ALT. #4 2:1 Side Slopes Concrete Lining	ALT. #5 Reinforced Box Convert	ALT. #6 Soil Bioengineering
Stop Erosion & Stabilize Banks		*	*	*	n/a	*
Clean Out Trash & Debris	*	*	*	*	*	*
Remove Fallen Trees	*	*	*	*	*	*
Safer & Healthier Area		*				*
Control Flooding		*	*	*	*	*
Timely Project Completion	*	*	*	*	*	*
Environmental Improvement		*			*	*
Aesthetically Enhancing		*			n/a	*
Meets Bank Stability & Hydraulic Efficiency		*		*	n/a	*
Minimize Property Loss	*				*	*
Financial Feasibility	*	*	*	*	*	*

Adapted from: Kimley-Horn & Associates (Sotir 1997a)

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Restoration of the Waukegan River Through Biotechnical Means

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Introduction

Many urban Illinois streams have been degraded as a result of streambank erosion, increased urban runoff, and increased channelization. Biotechnical stream stabilization techniques (BSST - Structures added to vegetation) were implemented on the Waukegan River to reduce the sediment load discharge to Lake Michigan originating from the river's eroded streambanks. The Waukegan River is located 30 miles northwest of Chicago, Illinois, in the City of Waukegan, Illinois (Figure 1). Best management practices (BMPs) were implemented on the Waukegan River in Washington Park and Powell Park, located in Waukegan. The Waukegan River Restoration Project was created to demonstrate whether the biotechnical techniques utilized were an effective means of resolving streambank erosion. The project was funded in part, by the United States Environmental Protection Agency (U.S. EPA), under the Section 319 Nonpoint Pollution Program of the Clean Water Act.

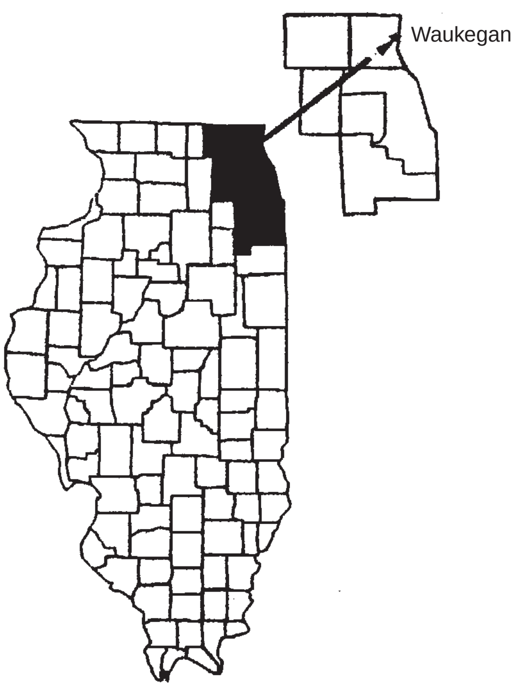


Figure 1. Waukegan River restoration project Section 319 National Monitoring Project.

At the selected severely eroded streambank sites, BSSTs were a more cost-effective and environmentally sensitive means of reducing nonpoint source (NPS) pollution than traditional approaches (i.e., rip rap, concrete lining).

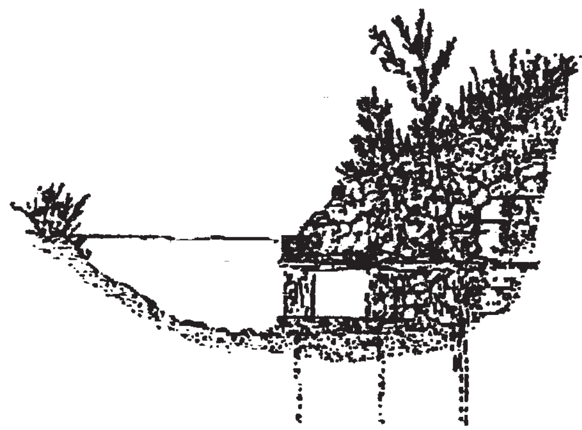
Biotechnical Designs

Installation of the first BSST occurred on the North Branch of the Waukegan River in Powell Park and in Washington Park during the fall of 1991. Lunkers and A-Jack structures were installed in Powell Park, while lunkers with stone were installed in Washington Park (Figure 2). On the two lunkers installations, vegetation (willows, dogwoods, grasses, and other wetlands plants) were placed into the lower, middle, and upper zones of the lunkers structures. The structures utilized were chosen to enhance in-stream habitat and provide a structural base for riparian revegetation of the bank. Advantages and disadvantages of using lunkers with vegetation are listed in Table 1.

The next installations of BSSTs were on the South Branch of the Waukegan River, in the fall of 1994, to control severely eroded streambanks in Washington Park. To address these eroded streambanks, lunkers, stone, dogwoods, willows, and grasses were installed. Other BSSTs that included coir coconut fiber rolls, willows, and grasses were implemented to treat specific small streambank erosion sites on the South Branch.

In the winter of 1996, seven low stone weirs (LSWs) formed by granite boulders were installed to create a series of pool/riffle sequences to enhance in-stream habitat on the Waukegan River. These LSWs were constructed to help resolve a lack of water depth, limited cobble substrates, and limited stream aeration in order to enhance the aquatic community in the Waukegan River at Washington Park.

Lunker Installation Design



A-Jack Design and Installation

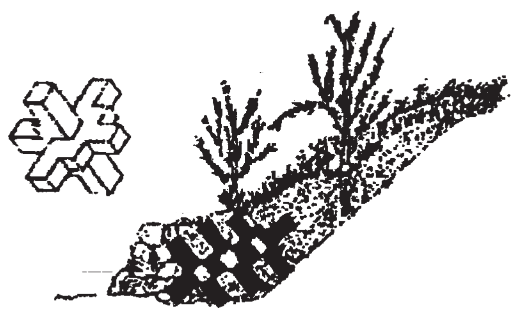


Figure 2. Biotechnical designs.

Table 1. Advantages and Disadvantages of Using Lunkers with Vegetation.

	Advantages	Disadvantages
A.	Provides greater public access to stream.	During first year, maintenance and revegetation are critical to project stability.
B.	Appearance of a natural stream functioning in an urban par is more appealling to the public.	Labor for lunker construction and installation is greater than riprap bank protection.
C.	Lower cost of installation.	
D.	Greater fishery benefits by increasing aquatic habitat for gamefish.	
E.	Maintenance operation requirements are revegetation, not construction activities.	

Monitoring

The Illinois EPA and the Illinois Department of Natural Resources are jointly monitoring the effectiveness of the biotechnical streambank techniques implemented on the Waukegan River. The U.S. EPA's National Monitoring Program (NMP) documents environmental benefits resulting from the BMPs implemented on the Waukegan River.

On the South Branch of the Waukegan River, protocols of the NMP were followed to detail the response of the stream fishery, the macroinvertebrate populations, and the in-stream physical habitat. The environmental quality of these three monitoring areas were evaluated utilizing the Index of Biological Integrity (IBI) for fisheries, the Macroinvertebrate Biotic Index (MBI) for benthic organisms, and the Potential Index of Biologic Integrity (PIBI) for in-stream habitat.

The monitoring plan divided the South Branch of the Waukegan River stream reach (Figure 3) into an upstream control (S2) and a downstream bank erosion site (S1) for biotechnical stabilization and in-stream habitat enhancement. This reach was chosen because no large ravine system transported urban runoff onto the stream between S1 and S2.

Between 1994 and 1997, the Waukegan River was monitored three times per year, once each in the spring, summer, and fall seasons. The monitoring activity documented

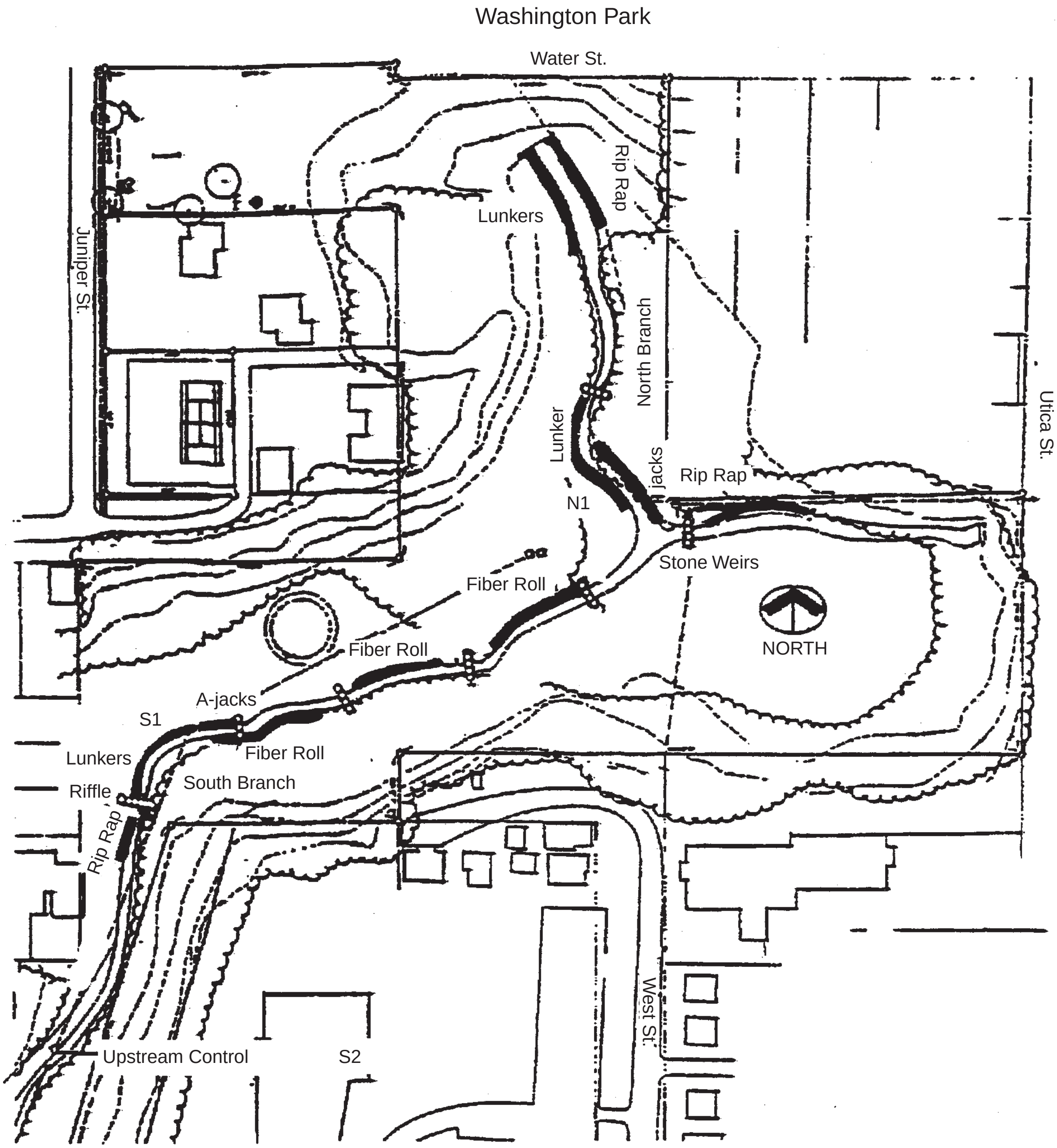


Figure 3. Map showing placement of erosion control techniques in the Waukegan River.

aquatic resources for one year before and one year after the biotechnical streambank stabilization and in-stream habitat enhancements were implemented. After the BSST application, the number of game fish species observed at S1 increased from four to five (Table 2). Following pool/riffle construction in 1996, the number of S1 game fish species increased to nine. Increased numbers of game fish and pollution intolerant fish species following the addition of the pool/riffle stream reach resulted in the IBI increasing from 26 to 35 (Table 3). The average number of fish sampled at S1 increased from 37 to 191 following lunker habitat enhancement and increased further, to 225, with the addition of the pool/riffle series. The upstream control (S2) remained a limited aquatic resource during the study period, with only 1-2 species present and an IBI of 28 or less during the entire monitoring period (Table 3). The average number of fish sampled at S2 varied between 16 and 69.

In 1996, the MBI indicated poor water quality at S2, with a value of 8.3 (Table 3), but better water quality at the S1 pool/riffle site, which remained in the non-limited classifi-

Table 2. Comparison of the Fish Species and Abundance for S1 and S2, for 1994 to 1996

	1994		1995 Lunkers		1996 Riffles	
	S1	S2	S1	S2	S1	S2
<u>Fish Species and Abundance</u>						
Game Fish						
Coho					2	
Bluegill					9	
Largemouth bass	1				12	
Longnose dace					44	
Mottled sculpin			4		2	
Fathead minnow	4	2	64	4	16	
Creek chub	1		8		8	
Golden shiner	1	2	17		2	
White sucker			24	7	28	
Pollutant Intolerant Fish						
Black bullhead					3	
Green sunfish					8	
Mosquito fish	27	13	20	4	2	1
Goldfish	1				1	
Brook stickleback			1		1	
Ninespine stickleback	1				3	
Threespine stickleback	1		53	54	84	15
No. of species	8	3	8	4	16	2
Abundance of fish	37	17	191	69	225	16

Table 3. Comparison of the Mean Station Values of the Indices for S1 and S2, for 1994 to 1996

	1994		1995 Lunkers		1996 Riffles	
	S1	S2	S1	S2	S1	S2
IBI	25.82	22.18	25.33	26.00	34.67	28.00
MBI	6.64	7.26	6.26	6.31	6.99	8.26
PIBI	41.51	41.93	41.93	41.79	41.34	41.65

cation with a value of 7.0, even with the same stream waters as S2. The MBI indicates that water quality did not limit or degrade aquatic resources in 1994 or 1995 (Table 3).

Physical habitat evaluations found deeper pools at the S1 station, while the S2 site remained very shallow. The LSWs were designed to transport bedload and scour pools during high flow events. PIBI scores remained constant for all three years and for both the S1 and S2 sites, however, ranging between 41 and 42 (Table 3). The PIBI scores are predicated on the absence of claypan or silt-mud substrates, the percentage of pools, and stream width. The S1 and S2 physical habitat had very little or no claypan substrate initially, which limited the expected change in PIBI.

A price comparison of the various types of bank stabilization are given in Table 4. The construction and installation techniques of lunkers make them relatively easy to use by volunteer citizens' groups. The relative costs of a rectangular concrete channel design, a riprap channel, a tri-lock channel, and lunker applications with vegetative stabilization can be estimated. The cost of a concrete culvert would include more design engineering support to determine possible offsite flooding effects. The design channel is 10 ft deep, 25 ft wide, and 300 ft long. The concrete channel would have a wall thickness of 10 inches.

This project demonstrated that BSSTs can be effective for reducing streambank erosion, by enhancing bank stability, and improving in-stream habitats. Incorporation of LSWs that created a pool/riffle series added to the in-stream physical diversity and resulting increased biodiversity. The project also demonstrated that LSWs are effective in increasing water aeration.

Streambank restoration is only one important step in improving the diversity of fish communities. LSWs provide additional pool depth and in-stream stone habitat necessary for higher quality fish communities in urban streams.

Table 4. Cost Per Foot of Various Applications

1. Lunker with vegetation	$27 per linear ft
2. Riprap with geofabric	$52 per linear ft
3. Tri-lock Channel	$165 per linear ft
4. Concrete Channel	$750 per linear ft

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Monitoring the Effectiveness of Urban Retrofit BMPs and Stream Restoration

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As a part of a larger Anacostia watershed restoration initiative, efforts have been underway since 1988 to restore Upper Sligo Creek. Over the past eight years, more than $2.0 million dollars have been spent on the restoration of Upper Sligo Creek and its environs. Upper Sligo Creek is a degraded, third order, urban Piedmont stream which flows through Montgomery County, Maryland. The general restoration strategy has featured the comprehensive employment of stormwater retrofits, instream habitat restoration, riparian reforestation, wetland construction and restoration, and native fish and amphibian reintroductions. Extended detention wet pond/marsh systems were employed on the basis of their ability to reduce pollutant loads and channel erosion and to create additional wildlife habitat. A prototype parallel pipe storm drain system was additionally used to divert first-flush stormflows away from an important feeder stream. Last, a wide variety of instream habitat enhancement structures such as rootwads, stone wing deflectors, boulder placement, log drop structures, etc. were employed. Restoration work was performed in Phase I and II of the three-phase project which covered the 1990-95 period. Biomonitoring of fish and macroinvertebrates was conducted before, during and after each construction phase. Physical habitat, hydrological and chemical conditions were monitored in Phase Ill. The number of established fish species residing in Upper Sligo Creek has risen from three species in 1988 to approximately 12 in 1997. Monitoring results were used to determine general retrofit effectiveness, adjust fish stocking strategies, document recruitment success and critique the overall effort.

Introduction

Attempts to restore the once highly degraded Upper Sligo Creek stream system exemplify the basic subwatershed restoration approach being employed throughout much of the urban, 400 kM^2 Anacostia River watershed. The completion of the Wheaton Branch stormwater management (SWM) retrofit facility in June, 1990 marked the beginning of a three-phased restoration project. The major objective of Phase I (1990-91) was to restore Wheaton Branch, Upper Sligo Creek's largest and most severely degraded tributary. The centerpiece of this effort was the three-celled, wet extended detention Wheaton Branch SWM pond/marsh. This SWM retrofit was designed to provide both a high level of water quality control and downstream channel erosion protection for a 326 ha (805 ac), 55% impervious catchment. Other major components completed under Phase I included restoration of 300 m of downstream aquatic habitat, the creation of two vernal pools for amphibian breeding habitat, and riparian restoration along a 350 m stream corridor.

Phase II (1992-94) restoration featured the completion of the University Boulevard SWM retrofit (a companion, two-celled wet extended detention pond/marsh). The SWM facility provides similar water quality and quantity control for a 162 ha (400 ac), 30% impervious drainage area. In addition, Phase II included: selective physical aquatic habitat restoration of approximately 7 km of the Upper Sligo Creek mainstem, construction of a 300 m-long parallel pipe stormflow diversion system along Flora Lane tributary, creation of a 0.1 ha marsh, riparian reforestation of 2 ha along Sligo Creek and the systematic reintroduction of 17 native fish species into Wheaton Branch, Flora Lane tributary and the Sligo Creek mainstem. Physical aquatic habitat conditions at 19 sub-project sites were enhanced via the employment of stone wing deflectors, boulder fields, rootwads, placed rip-rap, log drops, streambank bioengineering and cedar-tree brush bundles.

Because of the general lack of adequate surface stormwater runoff storage sites, physical aquatic habitat restoration of the Flora/Lane tributary necessitated a flow diversion approach. The prototype flow-splitting system was designed to divert stormflow generated from up to 90% of all one-hour storm events. Peak one-hour discharge from the 87 ha (216 ac), 50% impervious catchment is approximately 1.6 m3/s or 55 cfs.

Phase III (1994-95) included biological, physical habitat, hydrological and stream and pond water chemistry

[1] Project manager and co-investigator with James D. Cummins, Interstate Commission on the Potomac River Basin and James B. Stribling, Tetra-Tech, Inc.

evaluations. No major restoration construction work was performed in Phase III.

Study Design

Between March, 1990 and June, 1995, macroinvertebrate and fish monitoring was performed at a total of 10 sites to help assess the success of stormwater retrofit and stream restoration work on Sligo Creek's aquatic communities. Over this six-year period, the number of sampling stations grew from four in Phase I to eight in Phase II and finally, 10 in Phase III. Of the 10 sites, four were located in the Sligo Creek mainstem, two in the Flora Lane tributary, two within the restored portion of Wheaton Branch, one in the unrestored Woodside Park tributary and one in the SWM control comparison stream (i.e., Crabbs Branch, located in the neighboring Rock Creek watershed). In addition, a similar headwaters area of the neighboring, semi-rural Northwest Branch served as the Piedmont reference stream. Upper Sligo Creek restoration areas and monitoring station network are shown in Figure 1.

Stream water quality grab sampling was conducted between May, 1994 and July, 1995 at the following sites: Wheaton Branch - W131; Sligo Creek - SL2, SL3, SL4; Flora Lane tributary FL1 and FL2; and Crabbs Branch - C131. Paired baseflow and stormflow water samples for laboratory analysis were collected at WB1 and FL1 between June, 1994 and July, 1995. Monthly pond water column sampling of Wheaton Branch Pond No. 3 and the Crabbs Branch SWM facility was performed between May and November 1994.[2] As part of Phase III, sediment grab sampling was conducted at six locations: Wheaton Branch Pond No. 3, WB1, SL2, Sligo Creek mainstern above Flora Lane tributary, SL4 and FL1. Stream thermal regime characterization via continuous temperature monitoring was performed between May and November, 1994 at the following locations: SL2, W131, FL2, SL4 and CB1.

Methods

Macroinvertebrate sampling of riffle and pool habitats was performed using a square foot Surber sampler and long-handled D-frame net (595 micron mesh opening). Three Surber samples and a single D-frame sample were taken from riffle and pool areas, respectively. Specimens were identified to the lowest practical taxonomic level. Five metrics were calculated in the study: taxa richness, Hilsenhoff Biotic Index, EPT, percent contribution of dominant taxon and shredders/total.

Fish sampling was conducted via backpack electrofishing. Sampling techniques followed procedures present in Plafkin, et al. (1989) and as described in Cummins (1989) and (1991). The Zippin (1956) three-pass depletion method was used for fish population estimation. In addition, one-pass electrofishing was performed to further evaluate fish dispersion, taxa richness and recruitment success in Upper Sligo Creek.

Spot baseflow and stormflow water quality readings were made in the field using a Horiba U-10, multiprobe water quality meter and a Hach TDS meter. Paired baseflow and stormflow samples were collected for WSSC laboratory analysis from Wheaton Branch and the Flora Lane tributary. Baseflow samples were collected by immersing a 20-L polyethylene carboy in an undisturbed pool area. Stormflow samples were collected using a modified suspended sediment sampler.

Pond water column samples were collected at established representative surface, mid-level and bottom depths using a 2.0-L Van Dorn sampler. At the Wheaton Branch pond, one 4-L water sample was collected for laboratory analysis at each of the following depths: 0.15, 0.61 and 1.22 m.

An EPA priority pollutant scan of stream (pool) and pond sediments was performed by first taking 8-L of fine sediment with a coring device. Samples from three-to-five locations at each site were composited and delivered to Gascoyne Laboratories, Inc. for analysis.

Continuous stream temperature monitoring was accomplished through the systematic employment of Ryan TempMentor recording thermograph thermometers.

Physical aquatic habitat conditions were visually evaluated using both methods described in Barbour and Stribling (1991) as well as the Rapid Stream Assessment Technique (Galli, 1996).

Results

Stormwater Pond Influence

Both the Wheaton Branch and Crabbs Branch SWM facilities exerted a strong influence on downstream hydrology, water chemistry, temperature, substrate particle size and stream bioenergetics. As expected, water quality in both ponds was typically highest at or near the surface and declined with increasing depth (Table 1).

During the Phase III study period, Wheaton Branch's 1.1 rn release depth resulted in the periodic discharge of poorly oxygenated water high in organic materials and fine sediments (note: the pond's outlet structure was slightly modified in 1996 resulting in a mid-level release). Previous findings (Environmental Dynametrics, Inc., 1993) strongly suggested that during stormflow conditions this subsurface release functions as a siphoning device, effectively reducing the pond's overall pollutant removal efficiency. Of the stream sites monitored in Phase III, dissolved oxygen (DO) levels in Wheaton Branch were typically lower. DO concentrations there were below 5.0 mg/L on four out of the 30 sampling dates. The study's low stream DO reading

[2]Pond characteristics - Wheaton Branch: D.A. = 326 ha; imperviousness = 55%; permanent pool surface area 2.4 ha; bottom release design; maximum depth 1.75 m; constructed 1990; SAV absent; 24-36 hr ED control. Crabbs Branch: D.A. = 238 ha; imperviousness = 60%; permanent pool surface area = 3.1 ha; surface release design; maximum depth 2.60 m; constructed 1983. SAV (Hydrilla) covers approximately 75% of pond bottom; no formal ED.

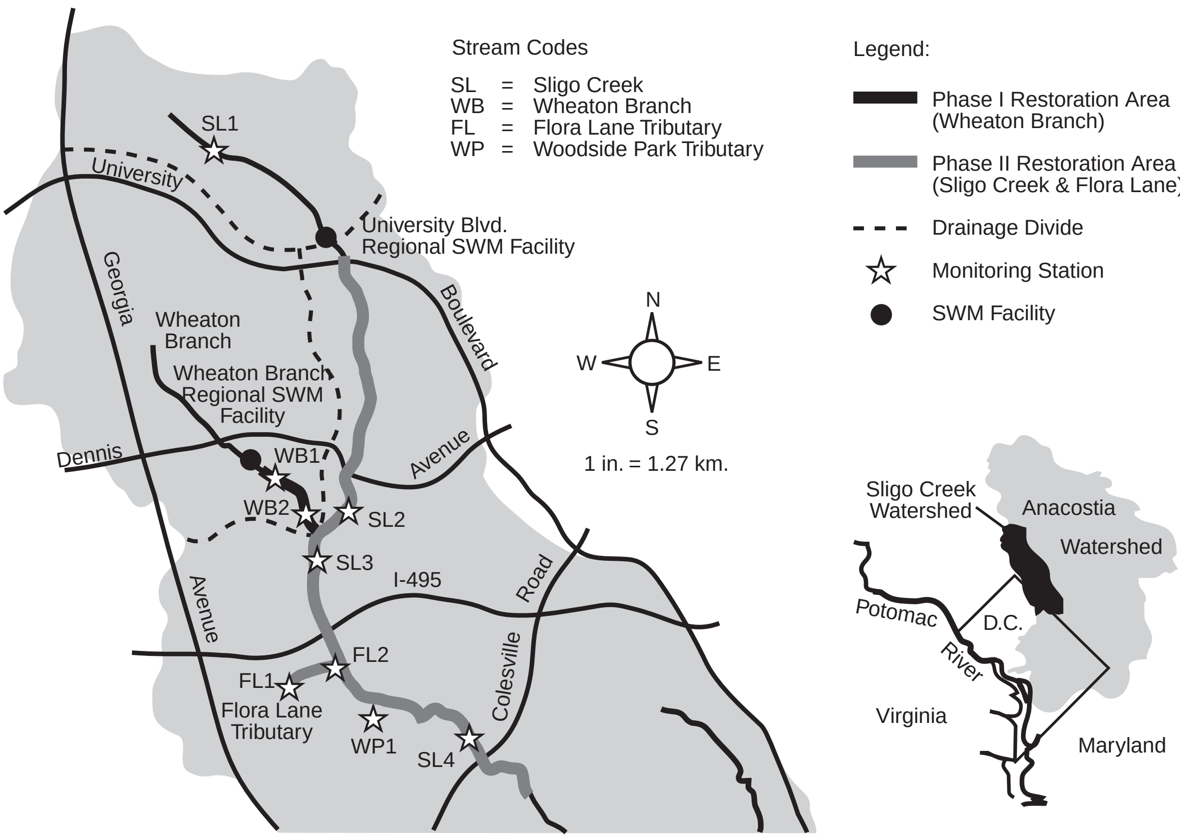

Figure 1. Upper Sligo Creek restoration and monitoring station network.

Table 1. Wheaton Branch and Crabbs Branch Pond Water Quality: June, 1994

Location & Date	Depth (m/ft)	Air Temp. (°C)	Water Temp. (°C)	DO (mg/L)	Field pH	Cond. (umhos/cm)	Turb. (NTU)	Secchi Depth (m)
Wheaton	0.15/0.5	32.0	28.5	12.13	7.30	146	16	0.50
Br. Pond	0.30/1.0		28.6	12.46	7.21	146	14	
No. 3	0.61/2.0		28.2	11.79	7.12	146	18	
(6/22/94)	0.91/3.0		27.5	5.93	6.72	147	17	
	1.22/4.0		26.5	1.20	6.53	210	34	
	1.45/4.5		26.0	0.23	6.21	227	34	
Crabbs Br.	0.15/0.5	32.0	28.4	12.73	8.77	300	11	0.72
SWM Pond	0.30/1.0		28.3	12.12	8.71	299	14	
(6/23/94)	0.91/3.0		27.8	10.44	8.51	294	13	
	1.22/4.0		27.0	3.75	7.26	298	14	
	1.83/6.0		23.0	0.22	6.60	423	139	
	2.59/8.5		25.2	0.11	6.57	595	87	

(2.87 mg/L) was recorded at both sites WB1 and W132 in June, 1994.

By comparison, Crabbs Branch's surface release design resulted in the discharge of warmer, yet clearer and more highly oxygenated water. The larger permanent pool surface area and volume and presence of extensive stands of Hydrilla verticillata (which cover approximately 75% of the pond bottom) contributed to Crabbs Branch's apparently better water quality performance.

Wheaton Branch and Flora Lane Tributary Stormflow Chemistry

Compared to Wheaton Branch, stormflow total suspended solids (TSS), total organic carbon (TOC) and biochemical oxygen demand (BOD) were generally slightly higher in Flora Lane. Median stormflow TSS, TOC and BOD concentrations were as follows: Wheaton Branch - TSS (20 mg/L), TOC (8 mg/L), BOD (9 mg/L); Flora Lane tributary - TSS (50 mg/L), TOC (10 mg/L), BOD(10mg/L). The median nitrate (NO_3) concentration was three times higher in Flora Lane (1.6 mg/L) than in Wheaton Branch (0.5 mg/L). Stormflow copper concentration ranges were nearly identical for both streams. The median stormflow copper concentration for both Wheaton Branch and Flora Lane was 20.0 ug/L. This median level was double that recorded under baseflow conditions. Mean stormflow total hardness concentrations for Wheaton Branch (80.3 mg/L $CaCO_3$) and Flora Lane (105.2 mg/L $CaCO_3$) were also considerably lower than under baseflow conditions.

Stream Sediment Chemistry

Results of the EPA priority pollutant scan revealed no high or unusual concentrations of pollutants in the sampled stream sediments and were deemed to not pose serious environmental toxic risks. Not surprisingly, the majority of contaminants found were associated with road runoff. For all metals detected, higher concentrations occurred in the Sligo Creek mainstern below the Flora Lane tributary confluence than above. For example, lead concentrations increased from 23 mg/kg above the Flora Lane confluence, to 50 mg/kg below. This enrichment is likely associated with the large volume of highway traffic and runoff from Interstate 495 and Georgia Avenue (MD Rte 97), which are conveyed via the Flora Lane tributary to Sligo Creek.

1994 Thermal Regime Characterization

Based on continuous water temperature monitoring results, the thermal regimes of the streams were generally categorized, per Galli (1990), as follows: 1) Sligo Creek mainstem - coolwater; 2) Crabbs Branch - coolwater bordering on warm; and 3) Flora Lane tributary - coolwater bordering on cold. Summer stream temperatures in all but the Flora Lane tributary regularly exceeded temperature levels considered optimal (i.e., less than 17-20° C) for many stonefly, mayfly and caddisfly species (Gaufin and Nebeker, 1973; Ward and Stanford, 1979; Fraley, 1979). Compared to Wheaton Branch, Crabbs Branch was typically 3-4° C warmer. This condition remained operative throughout the temperature monitoring period.

Physical Aquatic Habitat

Major aquatic habitat improvement occurred in Wheaton Branch following restoration work in April, 1991. Prior to this date, aquatic habitat at sites W131 and W132 was 49-56% of reference stream conditions. Following restoration, aquatic habitat at these two sites increased to 104-108% of reference. Similar improvements were documented in both the Flora Lane tributary and Sligo Creek mainstern upon completion of habitat enhancement work in February, 1994. Marked reductions in embeddedness levels were recorded throughout. Pre- and post- restoration embeddedness levels in Flora Lane fell from approximately 85% to 40%.

Macroinvertebrates

From Phase I to Phase II, both the number of individuals and number of taxa in Wheaton Branch and the Sligo Creek mainstern downstream of Wheaton Branch increased by approximately 50%. No discernible change was observed in the Flora Lane tributary. For the restored stream sites, the metric percent contribution of dominant taxon ranged from approximately 67-93% in 1990 spring samples to approximately 26-78% in 1995 (Table 2).

Fish

Between Phase I and III the number of established fish species increased as follows: Wheaton Branch - three to six; Flora Lane tributary - three to six; Sligo Creek mainstern - three to nine. Follow up, one-pass electrofishing results in 1996 and 1997 revealed that approximately 12 species are now established in the Sligo Creek mainstem. By comparison, Crabbs Branch and the reference stream support, 12-15 and 16-17 species, respectively. As seen in Figure 2, Index of Biotic Integrity (IBI) scores for restored sites SI-2, W131, WB2, SI-3, FL1, FI-2 and SI-4 all increased between Phase I and III (i.e., generally from poor to poor/fair). During Phase III, Crabbs Branch fish IBIs were consistently in the fair/good category.

Discussion

Monitoring results confirmed that the Upper Sligo Creek restoration produced several improvements in both biological and aquatic habitat conditions. These generally included: increases in the number of macroinvertebrate individuals (hence, improved food base for resident fish); reductions in percent contribution of dominant taxon; an increase in the number of established fish species from

Table 2. Calculated Macroinvertebrate Metric Values: Spring 1995* (modified from Cummins, et al., 1997)

Monitoring Site	Taxa Richness	Hilsenhoff Biotic Index	EPT	Percent Dominant Taxa	Shredders (Total)
SL1	7	7.8	2	63	0
SL2	10	6.5	3	47	0.01
SL3	9	7.0	3	26	0
SL4	10	6.9	3	30	0.12
WB1	11	6.8	3	46	0.006
WB2	7	6.3	3	78	0
FL1	2	8.0	0	67	0
FL2	6	7.3	2	48	0.05
WP1	3	8.1	0	61	0
CB1	10	7.0	3	43	0.007

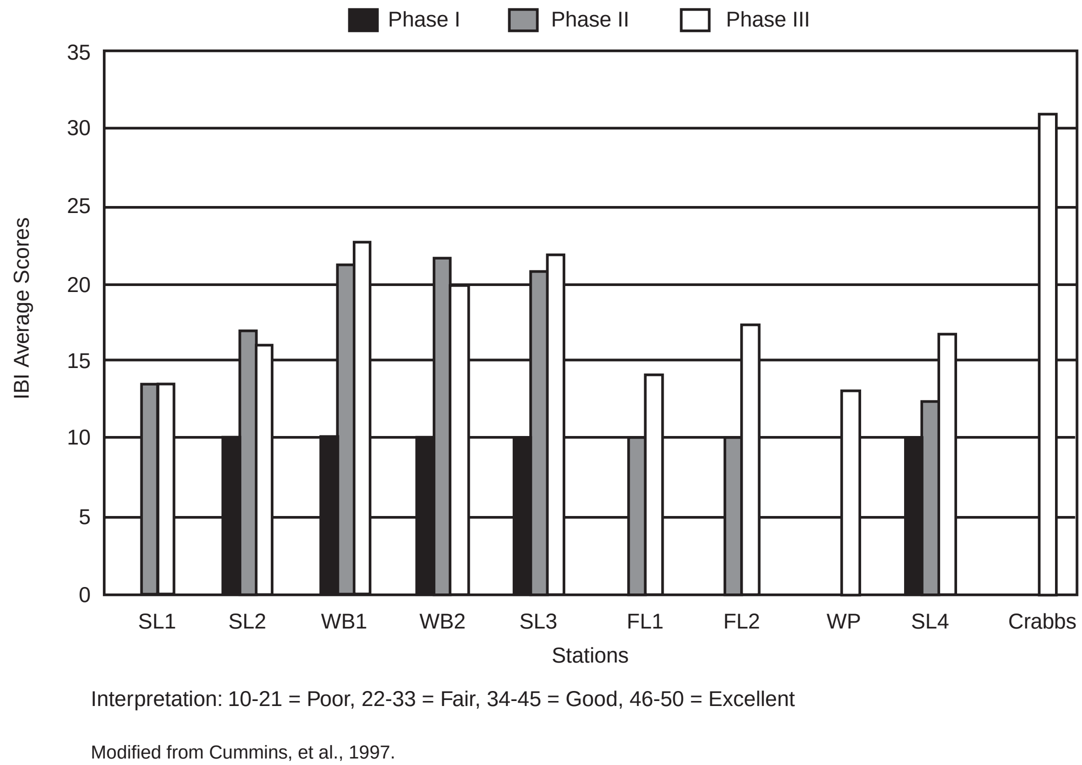

Figure 2. Summary: Upper Sligo Creek Phase I-III average fish IBI scores (modified from Cummins, et al., 1997).

three in 1988 to approximately 12 in 1997; reductions in streambed embeddedness levels and increases in overall riffle and pool quality; enhanced streambank stability; dramatic reductions in the amount of sediment, trash and debris present in the streams; a reduction in the incidence of fish deformities, skin erosions, lesions and tumors (DELTs) from 11% in Phase I to less than 3% in Phase III, and the ability to support relatively pollution intolerant fish species such as the mottled sculpin (*Cottus bairdi*), rosyside dace (*Clinostomus funduloides*) and northern hogsucker (*Hypentelium nigricans*) for periods as long as three years.

Despite these major improvements, the gain in Upper Sligo Creek's aquatic ecological health was generally limited to a shift from a very poor stream system to a fair one. At the end of Phase III, conditions were well below those found in the reference Piedmont stream. They were also generally lower than those present in Crabbs Branch. In addition, it was evident that both water quality and high runoff volumes remain a problem, particularly in the Wheaton Branch and Flora Lane tributaries. With regard to Wheaton Branch, the Wheaton Branch SWM facility's water quality control limitations appear to be hindering the re-establishment of a more diverse fish and macroinvertebrate community. In Flora Lane, the parallel pipe system is undersized. Consequently, approximately one to three times per year, high runoff discharges produce major streambed scouring. Episodic discharges of petroleum products into the stream, as well as the failure to perform routine sediment and debris removal at the parallel pipe system's control weir, have further limited stream recovery.

Conclusion

The effort required to shift the level of a severely degraded, intensely developed urban stream system to a higher level is not well understood, nor are results always linear. In the case of Upper Sligo Creek, the post-restoration aquatic community is still undergoing changes. Thus, additional monitoring, perhaps for another two to three years, may be required to more fully explain the recovery. Finally, continued efforts to reduce water quality and quantity-related problems are critical for further biological improvements and the ultimate restoration of the fish community to near-reference conditions.

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Urban Water Quality Monitoring and Assessment Approaches in Wisconsin

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The Wisconsin Department of Natural Resources is implementing a long-term urban monitoring strategy designed to support Wisconsin's Nonpoint Source and Stormwater Permit Programs. The purpose of the monitoring is to help ensure that management programs will improve the quality of Wisconsin's urban streams in the most cost-effective manner. At the core of the strategy are seven questions that we try to answer as part of preparing every urban nonpoint source control plan. All of the plans are enhanced with site-specific monitoring data for the first three questions, but the high cost of collecting monitoring data for the remaining four questions limits the data collection to special urban monitoring projects. Results are available for 26 special monitoring projects. To improve our answers to all of the questions, we are planning about 28 new special monitoring projects for the next five years. An urban runoff model and stormwater management manuals are used to transfer the results of special projects to other urban watersheds.

One or more types of monitoring data are being collected to answer each question. Biological data is collected in every urban watershed to answer the first two questions and part of question 3. The first three questions are: 1) what are the designated uses of the streams, 2) what are the problems in the stream, and 3) what are the pollutants and/or habitat factors degrading the streams? Special monitoring projects using biological, chemical and physical data attempt to answer the last four questions and part of question 3. The part of question 3 answered by special monitoring is what, if any, potentially toxic pollutants are degrading the streams. The last four questions are: 4) what are the sources of the pollutants, 5) what are the goals for reducing the pollutants and changing other factors degrading the stream, 6) what management alternatives will achieve the goals, and 7) what did the implementation of practices improve in the streams?

Introduction

Urban runoff has degraded many of Wisconsin's streams (Masterson and Bannerman, 1994; Simonson and Lyons, 1993). To improve and protect the quality of urban streams and other resources, Wisconsin's State Legislature created a Nonpoint Source Program in 1978. The program is implemented through "priority watershed projects," which include the preparation of a priority watershed plan. The priority watershed plan assesses nonpoint and other sources of water pollution and identifies best management practices needed to achieve the designated uses of the water resources.

The watershed plan guides the implementation of the best management practices. The Wisconsin Department of Natural Resources (WDNR) and the Department of Agriculture, Trade, and Consumer Protection administer the program, while the local units of government implement the plan. State funds are provided to cost-share the implementation of the best management practices recommended in the plan. Approximately 10 million is made available to municipalities every two years. Approximately 6 million is for the installation of urban practices and the remaining 4 million dollars is used for such activities as designing the practices, stormwater management plans, developing stormwater ordinances, and developing utility districts.

A priority watershed plan could not be prepared without the results from some type of urban monitoring activity. Results of the monitoring help us make the best management decisions to ensure that designated uses of the streams are achieved for the least cost possible. Monitoring data is used to strengthen our confidence in such decisions as identification of the pollutant sources and the selection of management alternatives. In response to this need for data, the WDNR has developed an urban monitoring strategy supported by two types of monitoring activities.

The purpose of this paper is to describe the monitoring strategy and some of the results from the monitoring activities. Information from the Lincoln Creek Subwatershed part of the Milwaukee South Priority Watershed Plan is described as an example of how the monitoring data is used to prepare the chapters in a plan. Future monitoring activities proposed for the strategy are also discussed.

Seven Stormwater Management Questions

The urban monitoring strategy is based on answering seven stormwater management questions (Table 1). Each question is related to the information needed for a chapter in the watershed plans. Chapter IV in the priority watershed plan for the Milwaukee River South Priority Watershed Project is entitled "Water Resources Conditions, Nonpoint Sources and Water Resource Objectives" (WDNR,1991). Designated uses and water resource objectives are usually the same. Results from questions 1 to 5 are needed to prepare this chapter. Answers to question 6 are helpful for making the management recommendations in Chapter V, which is entitled "Nonpoint Source Control Needs." The last question matches with the last chapter, Chapter VIII, entitled "Water Quality Evaluation Monitoring." Titles and order of the chapters might vary between plans, but they all cover the same types of information. These same questions would probably apply to almost any water resource management effort.

Table 1. Seven Stormwater Management Questions Used To Design Urban Monitoring Activities.

Question No.	Questions
1.	What are the designated uses of the urban streams?
2.	What are the problems in the stream?
3.	What are the pollutants and/or habitat factors degrading the urban streams?
4.	What are the sources of the pollutants?
5.	What are the goals for reducing pollutant loads and changing other factors?
6.	What management alternatives will achieve goals?
7.	What did the implementation of the practices improve in the urban streams?

All of the questions are important. The quality of the answer to a question depends to some degree on how good the answer is to the previous question. The order of the questions is the order in which they are usually answered. For example, selecting the best management practices without identifying the sources of the pollutants increases the risk of wasting money on the wrong practices.

Answers to the seven questions are also helpful in the implementation of the U.S. Environmental Protection Agency's Stormwater Permit Program. Priority watershed plans are available for many metropolitan areas in Wisconsin. Most municipalities required to have a stormwater permit are in a priority watershed. So far, some of the permit requirements overlap with the management actions specified in the watershed plans.

Two Types of Monitoring Activities Supporting the Urban Monitoring Strategy

Two types of monitoring activities are essential parts of the urban monitoring strategy. Results from the two types of monitoring activities are used to answer the seven management questions for all of the priority watershed projects. One type of monitoring is done for every priority watershed project. Biological data is collected in every stream to answer questions 1, 2, and parts of 3. Information about the designated uses, the problems in the urban stream, and the reasons for any problems are very site-specific. Parts of question 3 assessing the problems caused by conventional pollutants and a degraded fish habitat are included in the monitoring done for every stream.

There is no substitute for collecting good biological data in every watershed project. In most cases, it cost about $500 to collect the biological data in each urban stream. One or two sites in every stream are selected for fish, fish habitat, and macroinvertebrate sampling. The biological sampling for questions 2 and 3 is always done during the planning phase of a project, while the answer to question 1 is sometimes determined before the beginning of a watershed project.

The other type of monitoring provides data to answer questions 4, 5, 6, 7, and the part of question 3 evaluating the role of potentially toxic pollutants. These "special urban monitoring projects" collect data at a few selected sites that are then extrapolated to other urban areas. Special urban monitoring projects provide the kind of data needed by every priority watershed project, but which would be too expensive and time-consuming to collect for every project. Concentrations of zinc measured in street runoff in Madison, for example, is used to estimate zinc loadings from streets in Milwaukee. Testing the effectiveness of a best management practice in every priority watershed project would not only be unnecessary, but would cost over $100,000 to properly test each device. Results from three special monitoring projects were used to help answer the stormwater management questions for the Lincoln Creek Subwatershed.

Answers to Seven Questions for Lincoln Creek Subwatershed

Answers to the seven questions for the Lincoln Creek Subwatershed provide an example of how the information is presented in many of the priority watershed plans. Special urban monitoring project data used for the Lincoln Creek Subwatershed is also typical of the stormwater data available to a number of the priority watershed plans prepared before 1993.

Lincoln Creek Subwatershed is the largest urban subwatershed in the Milwaukee River South Watershed, draining 12,600 acres (18.8 sq. miles). Information about Lincoln Creek was collected as part of preparing the Milwaukee River South Priority Watershed Plan (WDNR, 1991). Residential land uses dominate this totally urban subwatershed. High density residential areas occupy 35% of the subwatershed, while 12% of the subwatershed is industrial. Lincoln Creek is almost entirely channelized with about one-third of the channel being concrete lined.

Lincoln Creek Answers - Questions 1 to 3

As for all the urban streams in the Milwaukee South Priority Watershed Project, biological sampling was done in

Lincoln Creek to answer questions 1, 2 , and parts of question 3 (Table 2). Electro-shocking of fish was done to develop an assessment of the fish community in Lincoln Creek. The WDNR's stream system habitat rating form (Ball 1982) was used to characterize the habitat in the stream. Thirteen factors, such as low flow, depth of pools, bank vegetation protection, lower bank deposition, and characteristics of bottom substrate and cover are ranked to determine the quality of the habitat. Habitat data are very important because they are a large factor in determining the potential fish species, composition, abundance, and age structure. Results from dissolved oxygen, temperature, pH, and bacteria surveys were combined with the ranking from the Hilsenhoff Biotic Index (HBI) for macroinvertebrates (Hilsenhoff 1982) to assess the water quality of the stream. All of the environmental data is then used to classify the stream.

Procedures developed by the WDNR are used to classify the urban streams for fish and other aquatic life (Ball, 1982; WDNR, 1995). Although the procedures are designed to provide a legal classification of a stream, classifications prepared for the priority watershed projects do not follow all of the required steps and, therefore, carry no legal authority. The stream use classes are (a) cold water communities, (b) warm water sport fish communities, (c) warm water forage fish communities, (d) limited forage fish communities, and (e) limited aquatic life. Recreational stream use classifications are also defined. For the purpose of designating fish and aquatic life uses, the biologist must decide if the factors limiting the ability of a stream to support certain uses are controllable or uncontrollable. If a controllable factor, such as urban runoff, is limiting the uses of a stream, the biologist can assume the urban runoff will be controlled to some degree when deciding what the potential uses of the stream should be. Although the procedures provide more objectivity to the process of classifying streams, professional judgement usually enters into the final use class selection.

Table 2. Answers to the Seven Stormwater Management Questions for Lincoln Creek Sub-watershed (from WDNR, 1991)

Question	Answer to Questions
1. What are the designated uses?	*Fishery Use*: Below Teutonic Ave. - warm water sport fish; other natural reaches - limited forage fish; and concrete lined reaches - limited aquatic life *Recreational Use*: All reaches - partial body contact
2. What are the problems in the stream?	*Fishery Use:* Species diversity - 2 (Ref. stream -20) *Macroinvertebrates:* Severely impaired *Recreational Use:* Partially meeting use
3. What are pollutants and/or factors degrading the stream?	*Pollutants*: Sediment, potentially toxic pollutants (eg. lead, zinc, and copper) in water column and bottom sediments, *bacteria, and low dissolved oxygen.* *Factors*: Poor habitat, flashy flows, and concrete lining.
4. What are the sources of pollutants?	*Sediment*: Established urban area - 29%; construction sites - 64%; and streambanks - 7%. *Lead:* High density residential - 33%; industrial - 32%; Multi-family residential - 19%; and commercial - 14% *Bateria and low dissolved oxygen* - no entry
5. What are goals for reducing pollutant loads and changing other factors?	*Flow Rate and Volume*: Reduce enough to control bank erosion and scour. *Sediment:* A 50% reduction in sediment *Lead:* 40% to meet acute toxicity standards at outfalls and 50% to meet chronic toxicity standards in stream.
6. What management alternatives will achieve the goals?	*Sediment:* Construction site erosion controls designed to reduce the sediment by 75% *Lead:* Wet detention ponds or their equivalent to control all of the runoff from critical land uses (industrial, commercial, freeways, high density residential, and multi-family residential). *Flow Rate and Volume:* No entry
7. What did the implementation of the practices improve in the stream?	Develop long-term biological, chemical, and physical monitor ing program.

Not all of question 3 was answered by biological monitoring. Although problems caused by excessive sediment, and sometimes high nutrient loadings, can be identified by the fish habitat surveys, some grab samples of Lincoln Creek water were used to identify the presence of potentially toxic pollutants. We recommend raising public awareness about the potential problems with toxic pollutants and bacteria by collecting grab samples below a storm sewer outfall during three different runoff events. These samples should be analyzed for as many of the pollutants found in stormwater as possible, such as heavy metals and fecal coliform bacteria.

Lincoln Creek Answers - Questions 4 to 6

Lead is the potentially toxic pollutant that is assumed to represent all of the other potentially toxic pollutants in the answers to questions 4 through 6. Lead is also important to part of the answer for question 3. Extensive stormwater monitoring of eight storm sewer outfalls in the City of Milwaukee identified the types of potentially toxic pollutants that might be in the stormwater discharging to Lincoln Creek

(Bannerman, 1983). Results of this special urban monitoring project were available for samples collected at high density residential, medium density residential, commercial strip, and shopping center monitoring sites. Total recoverable lead event mean concentrations exceeded the acute toxicity standard (hardness of 100mg/l) of 170 ug/l for 90% of the runoff events sampled at a commercial landuse site (WDNR, 1989). Although the WDNR does not currently regulate stormwater discharges using numeric effluent limitations, acute and chronic toxicity standards applied to point source discharges for industries and municipalities are useful to characterize the potential importance of different pollutants to the quality of urban streams. Bottom sediment samples collected for a special urban monitoring project in the nearby Menomonee River indicated that all urban stream bottom sediments are probably contaminated with heavy metals (Dong, 1979).

Sources of lead and sediment for the established urban areas were estimated using an urban runoff model called *Source Loading and Management Model* (SLAMM) (Pitt, 1989). SLAMM is widely used in Wisconsin as a planning tool to better understand sources of stormwater pollutants and their control. Percent contributions listed in the answer to question 4 are a lot more credible because SLAMM was first calibrated with the data from the 1983 Milwaukee stormwater monitoring project. Once the model was calibrated it was also used to estimate the pollutant reduction goals. An average annual lead concentration calculated with SLAMM for all the outfalls in Lincoln Creek subwatershed was compared to the acute toxicity criteria for lead. About a 40% reduction in lead loading was needed from all the critical landuses in the subwatershed to meet the acute toxicity standard in the stormwater discharged from the outfalls. Concentrations measured in the Milwaukee River were used to determine the exceedances of the chronic criteria in the stream.

Two years of samples collected at the inlet and outlet of a wet detention pond in Madison, was the basis of the answer developed for question 6 (House, 1993). The results of this special urban monitoring project confirmed that about a 90% reduction in sediment and about a 60% reduction in lead could be achieved with wet detention ponds.

Lincoln Creek - Question 7

Lincoln Creek is part of an intense evaluation monitoring effort in Wisconsin. Comprehensive biological, chemical, and physical monitoring is being done for at least a ten-year period. Results from Lincoln Creek will be used to evaluate the benefits of implementing best management practices in other urban streams. All of the pre-practice installation monitoring has been completed for Lincoln Creek.

Special Urban Monitoring Projects

Results from the three special urban monitoring projects referenced above were available in time to enhance the answers to the seven stormwater management questions in the Lincoln Creek Subwatershed. None of these projects were conducted as part of preparing the Milwaukee South Priority Watershed Plan. Determination of pollutant reduction goals would have been more difficult if the monitoring data had not been available from the 1983 Milwaukee stormwater monitoring project. Although there was insufficient data in these three projects to completely defend the answers to the questions, it was enough to begin an implementation effort for Lincoln Creek.

A total of 26 special urban monitoring projects have been conducted by the WDNR over the last 17 years. Each one of the projects was selected to help answer one or more of the seven stormwater management questions. All but five of the projects were completed after 1993. This is after the time priority watershed plans had been prepared for most of the major metropolitan areas in Wisconsin. More recent priority watershed projects have used the results of the later special monitoring projects.

All together, the special monitoring projects cost about $2.5 million. These costs were shared by the WDNR, EPA, and local units of government. Between five and eight projects are completed for each of questions 3, 4, 6, and 7. Our difficulties in selecting goals for reducing pollutant loads and changing other factors, such as flow volumes, is reflected in the fact that data is available for only two projects related to question 5. A report is available for all of the completed special monitoring projects. Since biological monitoring is done in every watershed project for questions 1 and 2, there are no special projects completed for these questions.

Role of Toxic Pollutants in Urban Streams - Question 3

Five special urban monitoring projects are completed that help characterize the impact of potentially toxic pollutants on the biological integrity of an urban stream. Three of the projects evaluated the toxicity of stormwater in Lincoln Creek. A total of 316 laboratory toxicity tests were performed on stormwater and baseflow samples with *Ceriodaphnia dubia, Daphnia magna,* and *Pimephales promelas.* No short term, 48-96-hour acute or 7-day chronic toxic effects, which could be solely attributed to stormwater runoff, were identified with the three laboratory test species (Ramcheck, 1995). Subsequent toxicity tests were modified to include longer-term *in situ* tests. Tests with *D. magna* performed in flow-through aquaria showed significant increases in mortality for 93% of the tests after 14 days of exposure (Crunkilton, 1996). Longer exposures of 17 to 61 days, with juvenile and adult *P. promelas* exhibited significant increases in mortality ranging from 30 to 95%. It appears that conventional wastewater effluent toxicity tests lack the sensitivity to detect the biological degradation observed in Lincoln Creek. The long-term *in situ* toxicity tests should be used for future special monitoring projects evaluating the toxicity of stormwater.

An *in vitro* bioassay with PLHC-1 (*Poeciliopsis lucida*) fish hepatoma cells was used to assess potential toxic potency of aryl hydrocarbon receptor (AhR) - active compounds, collected by semipermeable membrane devices (SPMDs) exposed to Lincoln Creek water (Villeneuve,1997). Dialysates from SPMDs exposed to Lincoln Creek water caused marked cytochrome P4501A induction in PLHC-1. SPMDs exposed to baseflow had consistently lower potencies than those exposed to high flows. Emperical evidence suggests that AhR-active polycyclic aromatic hydrocarbons (PAHs) can account for about 20 to 50% of the potency observed.

Monitoring of several urban streams in Milwaukee County, showed that the urban streams are highly degraded (Masterson, 1994). Stormwater discharges are blamed for high concentrations of pollutants in the water and bottom sediments, flashy flows, poor habitat, low diversity of aquatic organisms, and accumulation of pollutants in fish and crayfish tissue. A reference site was used to determine the degree of degradation. Water quality data compiled from four stormwater monitoring projects showed the concentrations of many potentially toxic pollutants are high enough to say that stormwater might be contributing to the degradation of the urban streams (Bannerman, 1996). All these findings describe the complexity of developing a solution to problems caused by stormwater.

Sources of Pollutants - Question 4

Results from six special urban monitoring projects are available to help determine the sources of stormwater pollutants. All but one of these projects provides data on the concentrations of pollutants in the runoff from different urban source areas. New sampling equipment was developed to collect sheet-flow runoff samples from roofs, parking lots, driveways, streets, industrial yards, and lawns. Source areas were sampled in residential, industrial, and commercial landuses. The relative importance of the pollutant load from each source area varies by pollutant and landuse. Study sites in Madison, WI, and Marquette, MI, showed streets as an important source for most pollutants and landuses (Bannerman, 1993; Burnhart, 1993; Waschbusch, 1998; Steuer, 1997). Lawns are an important source of phosphorus for all the study sites, while roofs contribute a relatively large amount of zinc in commercial and industrial landuses for the Madison study sites. Parking lots at the Marquette study site are contributing the largest amount of PAHs.

Not only the results from these projects identify important source areas for the study sites, but the data from these projects is also being used to calibrate SLAMM. This will increase our confidence in source area loadings determined for future priority watershed plans. Data from these projects are also helping us identify the activities responsible for depositing the pollutants on the different urban surfaces. For example, phosphorus concentrations in the runoff from streets increased with the greater percent tree canopy over the street (Waschbusch, 1998). This information will be used to make the model more sensitive to the tree canopy variations around a city. To more accurately model the runoff from lawns, runoff parameters were measured using a rainfall simulator on 20 Madison lawns (Legg,1996). Rainfall-runoff relations vary substantially between lawns, while the lawns that have been established less than three years produce much higher runoff volumes than older lawns.

An important number in every priority watershed plan is the comparison of agricultural and urban contributions of phosphorus and sediment to a stream. Stream phosphorus and sediment loads compiled from watersheds around the state indicated that the phosphorus unit-area loads in the southeast part of the state are similar for agricultural and urban landuses (283 and 318 lbs/sq. mi., respectively) (Corsi, 1997). Sediment unit-area loads are three times higher for the urban areas. A simple calculation with these numbers will be used to determine the importance of controlling urban sources of phosphorus and sediment.

Pollutant Reduction Goals - Question 5

Question 5 is probably the most challenging of the questions to answer, but it has received the least amount of attention. An inadequate answer to this question can greatly lower confidence in the suggested solutions to the stormwater problems. An interim method for predicting pollutant reduction goals is to combine the output of SLAMM with a probabilistic dilution model developed by the EPA (Corsi, 1995). A test of the method in Lincoln Creek demonstrated a reasonable agreement between the median measured and predicted event mean suspended solids concentrations. Pollutant loading reduction goals can be determined by reducing the pollutant loading output from SLAMM until the median event mean concentration in the stream is below the water quality standard. SLAMM loads are reduced by simply specifying a control in the model run.

The approach that will eventually replace using a probabilistic dilution model will be based on understanding the relationships between urban landuse activities and the conditions in the streams. An investigation of 103 streams in Wisconsin showed that a high amount of urban land use in a watershed is strongly associated with poor biotic integrity and weakly but significantly associated with poor habitat quality (Wang, 1997). There seemed to be a threshold value of the urbanization between 10 and 20% beyond which IBI values are consistently low. Performance standards based on observed threshold values can become the basis for setting pollutant and water volume reduction goals for urban streams.

Selection of Best Management Practices - Question 6

Having eight of the special monitoring projects, the study of best management practices has received the most attention. Monitoring data is available on the pollutant removal effectiveness for a wet detention pond, a multi-chamber treatment train, a Stormceptor, and street sweeping. A model was developed to test the removal effectiveness of infiltration devices. All of these types of practices are being used in Wisconsin. Two other projects summarized the costs of implementing different best management practices and the methods for monitoring industrial sites.

More monitoring data appears to be available for wet detention basins than any other type of practice. They are probably the most commonly used structural practice in Wisconsin. Results from monitoring a wet detention basin in Madison, indicate that a well-designed basin should remove about 90% of the solids, 50% of phosphorus, and 60% of heavy metals (House, 1993). The pond's sediment and associated pollutant removal efficiencies are both influenced by influent particle size distributions (Greb, 1997). Concentration data collected at the outlet occasionally exceeded the acute toxicity standards for zinc and copper. Toxicity testing on a pilot-scale wet detention basin indicated that toxic reduction goals might not be achieved by just using basins (Kron, 1998). Mortality for *P. Promelas* exposed to the treated Lincoln Creek stormwater was significantly reduced in only one of four test periods.

Evaluations of a multi-chamber treatment tank and a Stormceptor installed at city maintenance yards revealed very different pollutant removal efficiencies. The multi-chamber treatment tank achieved levels of control for many constituents of between 80 and 95%, while the efficiencies for the same constituents in the Stormceptor ranged from 20 to 30% (Greb, 1998). Both devices will easily retrofit into most land uses.

The water quality benefits of using mechanical street sweepers was evaluated at four paired test sites in Milwaukee County. Models developed during the project were used to determine street sweeping efficiencies for different times of the year. Street sweeping is most effective in the early spring during the heaviest street loads of the year and in the fall following leaf fall (Bannerman, 1983). Limited benefits are expected from any intensive sweeping program the rest of the year. Newer high efficiency sweepers are expected to perform better than the mechanical sweepers used in this study (Sutherland, 1997).

Although infiltration devices are rarely retrofitted in Wisconsin, they might be needed to some degree to fully accomplish our pollutant and water volume reduction goals. One concern about using infiltration as a practice is the potential threat to groundwater quality. A method for determining the potential mobility of 32 organic and seven inorganic pollutants during the infiltration of stormwater was developed (Armstrong, 1992). The main variables affecting leaching of stormwater pollutants are soil type selection, depth to groundwater, and water loading rate. Under high loading rates, a few meters of soil will probably not provide adequate protection of the groundwater. Inorganic pollutants (mostly metals) are less mobile than organic compounds (pesticides and PAHs). The calculated residence times per meter of soil for organic chemicals in a hypothetical infiltration system range from 15 days or less for "mobile" compounds to over 1,000 years for "very low mobility" compounds. These calculations assume a high water loading rate to the infiltration device. Predicted residence times for inorganic pollutants in a 1.0 meter soil layer subjected to a water infiltration rate of 60 meters per year range from less than 1 year for chromium to over 100 years for lead.

Costs of stormwater practices are sometimes difficult to estimate because not many of some types of practices have been installed in Wisconsin, and the costs of the ones that have been installed are not well documented. Not knowing the costs of the practices makes it very difficult to select cost-effective management alternatives for established urban areas. Some estimates of the capital and annual operation and maintenance costs are available for a number of practices (SEWRPC, 1991).

Different sampling methods are being used to test the effectiveness of stormwater practices designed to improve the quality of runoff from industrial sites. Evaluation of the effectiveness of the industrial practices will be difficult unless more is known about how the sampling methods can affect the interpretation of the data. Five different monitoring methods were tested at five different industrial sites (Roa-Espinosa, 1994). These five methods were (1) flow weighted composite, (2) time discrete, (3) time composite, (4) source area, and (5) first 30 minutes. Assuming that sampling at the outfall is the most representative sample, then time composite sampling is the best method. However, a new type of electronic source area sampler could make source area sampling a better choice, because the samples are collected closer to the source of contamination.

Results from testing the effectiveness of different best management practices is used to calibrate SLAMM. Practices not available in SLAMM, such as the multi-chamber treatment tank, are added to the model. The new effectiveness data will also be used to update the information about each practice in Wisconsin's stormwater manual (WDNR, 1994). Average long-term rainfall conditions for several regions of the state are used to run the model (Corsi, 1996).

Evaluation Monitoring - Question 7

The ability of the stormwater best management practices to achieve the designated uses in a stream is being determined for Lincoln Creek and the Menomonee River in Milwaukee County. Frequent chemical, biological, and physical monitoring being done for both streams. Plans are to continue the monitoring until implementation of the priority watershed projects is completed. Results from these two streams will be extrapolated to other urban streams. At a cost of about $40,000 per year for each stream this kind of intensive monitoring cannot be accomplished in all the priority watershed projects. All of the pre-practice installation monitoring is done for both streams. Results of the pre-practice installation monitoring have clearly documented the degradation of the water quality and biology in both streams (Wang, 1996; Owens, 1997). Several common statistical techniques have been tested to detect changes in the water chemistry data (Walker, 1993). The application of non-parametric tests to regression residuals for storm load data appears to be the best approach for estimating minimum detectable change for a known or estimated "before" condition.

To help quantify the changes in the stream, a version of the Index of Biotic Integrity (IBI) was developed for warm water streams in Wisconsin (Lyons, 1992). Guidelines were developed for evaluating fish habitat in Wisconsin streams (Simonson, 1994).

Future Urban Monitoring Plans

Results from the completed special monitoring projects greatly increased the amount of information available to answer the seven stormwater management questions. In any new plan, however, we could not totally defend the answers to the seven stormwater management questions; if lead is targeted as a pollutant to control, for example, we still could not totally defend its role in the degraded biology or the levels of lead reduction suggested in the plan. Without good monitoring data, each implementation effort is to some degree an experiment, whose results will probably not be known until it is too late to make any major adjustments to the types of best management practices implemented.

Having the right kind of monitoring data can also influence people's acceptance of the solutions offered in a priority watershed plan. Whenever municipalities, industries, and others cooperating in the stormwater clean-up effort have some doubts about the answers to the management questions, it diminishes the chances of completely implementing the priority watershed plan.

Future Products

Our experience with finding answers to the seven stormwater management questions gave us some ideas on the type of additional information we need to improve our answers. We identified eight products we need to develop using special monitoring projects (Table 3). All the products are important, but developing biological criteria and stormwater performance standards for urban streams would probably give the biggest boost to the credibility of our answers. We would like to set a goal of having all of the products over the next five years. Realistically, it will probably take longer to develop stormwater performance standards.

Biological criteria are needed to quantify a potential use of every stream. This should be less subjective than the stream classification procedures we follow now to determine the uses of a stream. A set of indices, such as the IBI and the HBI, would identify the potential use of the urban streams in every Wisconsin sub-ecoregion. Development of the criteria would be a five-year effort requiring the collection of data in both rural and urban streams. Some of the data needed is already in WDNR files.

Closely related to the biological criteria is the identification of the pollutants causing a toxic response in urban streams. Toxic pollutants could be a limiting factor in the selection of best management practices. Although a toxic effect has already been identified in one urban stream, it is not known which pollutants are responsible for the observed toxicity or what degree of urbanization is required to cause a toxic response. Using methods already developed, it would probably take about three years to develop an understanding of which pollutants are toxic and how the amount of urbanization effects their toxicity.

Table 3. Products to be Developed using Future Special Urban Monitoring Projects

Question No.	Products
1	Biological Criteria for urban streams.
2	None
3	Method to identify which toxic pollutants are important in each stream and what levels of control are needed.
4	SLAMM calibrated for all source areas and all the problem pollutants.
5	Stormwater performance standards designed to achieve biological criteria - standards based on % connected imperviousness, flow rates and volume, D.O. levels, buffers, pollutant loadings, and temperature.
6	Method of selecting most cost-effective practices to achieve performance standards. SLAMM capable of testing all practices. Stormwater manual describing suggested management alternatives for the most commonly occurring land use mixtures.
7	Location to showcase benefits of stormwater management.

SLAMM is calibrated for many of the pollutants washed off many of the source areas. But more calibration is needed for the toxic pollutants in runoff from some of the source areas, especially gas stations, parking lots, and industrial paved surfaces. A three-year monitoring effort using our existing source area monitoring methods would produce the numbers to finish the calibration of SLAMM.

A performance standard is a threshold value for a biological, chemical, or physical factor that, if achieved, will help meet biological criteria for a stream. The threshold values are for the factors that affect the biological integrity of any stream. At least seven types of performance standards need to be developed to meet the biological criteria or improve the biological integrity of a stream. They include maximum temperatures, minimum dissolved oxygen levels, minimum and maximum flows, maximum water volumes, types of riparian vegetative buffers, annual sediment loading, and the combined annual loading of problem toxic pollutants. Percent connected imperviousness is also included as a factor because it is a good way of combining the effects of all factors without having to understand the effect of each one. Target values for all of these factors would be the basis for developing management alternatives. These target values will probably vary between sub-ecoregions. The difference between the performance standards for a stream and the existing values for these factors determines the goals for reducing pollutants or changing other factors.

A multi-variate statistical analysis is going to be done to determine the importance of each one of these factors. A great deal is already known about threshold values for some of the factors, especially flow, temperature, and dissolved oxygen (Raleigh, 1986). Most of the monitoring over the next five years will be designed to better understand the threshold values for percent connected imperviousness and pollutant loadings. Work has already started on the percent connected imperviousness factor with the collection of biological data from 45 streams with different degrees of urbanization. A less expensive method is being developed to estimate annual pollutant loadings. Data collection has started on a project to calibrate a model designed to predict stream temperature changes during a runoff event in an urban area.

Another important product is the development of cost-effectiveness curves for different management alternatives. Cost-effectiveness would be based on pollutant removal relative to different annual costs of the alternatives. Usually, a combination of practices would be included in each alternative. Curves might vary by land use and/or type of pollutants being controlled. The curves would identify the least expensive alternative for the level of control desired.

All the most promising best management practices will be tested in Wisconsin. A special emphasis will be put on infiltration and filtration devices. We will also try to document the water quality benefits of educating the public on stormwater management. All the results of these efforts will be used to calibrate SLAMM and update our stormwater management manual.

Every environmental management program needs some place to showcase the benefits of their efforts. This will be essential to justifying the long-term funding commitments required by municipalities, industries, and other groups responsible for stormwater management. Although evaluation monitoring has already began at Lincoln Creek and the Menomonee River, at least one more site is needed. We are looking for a site where a good quality stream in an urbanizing area could be saved by the proper use of best management practices.

Future Types of Special Urban Monitoring Projects

A lot of monitoring is going to be required to produce all eight products. It is difficult at this time to describe all the types of special monitoring projects that will be needed to develop the eight products, but it is useful to suggest a list of projects. About 28 special monitoring projects should provide enough information to develop the products we need (Table 4). Completion of all these projects will require at least five years or more to complete for a cost of at least $4.5 million. Work has already started on five of these projects. Most of the other projects are just at the suggestion stage.

Table 4. Future Special Urban Monitoring Projects

Question No.	Monitoring Projects
1	a. Collect biological data at test and reference sites in all sub-ecoregions. b. Develop IBI for small warm water streams.
2	None
3	a. Test response of organisms to different toxics in stormwater. b. Test response of organisms to serial dilutions of problem toxics. c. Test toxic response in streams with different % connected imperviousness.
4	a. Test electronic sheet flow sampler. b. Collect runoff from all source areas in three WI ecoregions. c. Measure runoff coefficients for lawns in three WI ecoregions. d. Evaluate relationship between lawn characteristics and amount of runoff. e. Measure pollutant concentrations for streets with different traffic volumes. f. Measure street phosphorus levels for streets with different tree canopy. g. Measure accumulation and washoff functions for street solids. h. Measure pollutant loadings during snowmelt.
5	a. Calculate amount of infiltration needed to maintain normal baseflows. b. Measure effect of excess runoff volumes on fish habitat. c. Collect all types of data in streams with different degrees of urbanization. d. Calibrate temperature model. e. Evaluate importance of flow, habitat, chemistry to quality of stream. f. Evaluate importance of different buffer widths to stream quality. g. Determine how many grab samples are need to estimate annual loading.
6	a. Measure effectiveness of two infiltration devices. b. Measure effectiveness of high efficiency sweepers. c. Measure effectiveness of two filtration devices. d. Measure benefits of public education. e. Summarize cost of building and maintaining all types of practices. f. Calibrate selected flow model. g. Test controls by using historical and new fish data from urbanizing areas.
7	a. Measure use changes in urban and urbanizing streams.

Projects already started include (1) development of IBI for small warm water streams, (2) determining the relationship between percent connected imperviousness and stream quality indicators, (3) calibration of a model to predict temperature changes in an urban stream during a runoff event, (4) developing a less expensive method of determining annual pollutant loads, and (5) evaluating benefits of implementing practices in urban streams.

Summary

A combination of some monitoring in every urban stream and special urban monitoring projects is helping Wisconsin retrofit urban best management practices that achieve the designated uses of the streams for as little cost as possible. All the monitoring activities have been designed to answer seven stormwater management questions. Each question relates to a type of information needed to complete one or more chapters in a priority watershed plan prepared for Wisconsin's Nonpoint Source Program. Biological monitoring done in every urban stream identifies the designated uses and the reasons for any of the observed problems. Special urban monitoring projects enhance the answers to the first three questions, such as identifying the potentially toxic pollutants, and provide answers to the last four questions. Results of special projects to determine the sources of pollutants and the effectiveness of best management practices are most used results in the priority watershed plans completed over the last ten years.

Results are available from 26 special urban monitoring projects completed over the last 17 years for a cost of about $2.5 million. Most of these projects were completed after 1993. These results provide excellent answers to parts of larger problems; others parts of those problems remain unasked or unanswered. More information is especially needed to determine goals for each priority watershed project and to determine the best management alternatives. Although it is important to continue the efforts to retrofit urban areas with what we know, it is also important to lower the risk in making future management decisions by conducting additional monitoring projects.

Twenty-eight new special urban monitoring projects resulting in eight essential products are recommended. Development of biological criteria and performance standards for urban streams are two of the products essential to the success of future stormwater management efforts. Work has already started on five new special monitoring projects. These projects will help define the use of "percent connected imperviousness" as a performance standard and provide a method for predicting the changes in stream temperature during a runoff event. Another project will document the changes in two urban streams during and after the implementation of best management practices. Municipalities, industries, and other groups cooperating in the stormwater management efforts will be able to use the results of these and other new projects to improve their confidence in management decisions that could cost millions of dollars.

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Considerations and Approaches for Monitoring the Effectiveness of Urban BMPs

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The purposes of this paper are to 1) describe some of the problems with typical Best Management Practice (BMP) monitoring and effectiveness reporting and to 2) suggest the utilization of consistent stormwater monitoring techniques. This will allow the data collected on the effectiveness of individual best management practices (BMPs), including retrofit BMPs, to be useful for a particular site, and to also be useful for comparing studies of similar and different types of BMPs in other locations. Many BMP effectiveness studies in the past have provided only limited data useful for assessing BMP design and selection on a wide scale. This paper overviews some of the problems of past BMP effectiveness studies from the perspective of comparability between studies. It suggests some of the ways that data could be collected to make it more useful for assessing factors (such as settling characteristics of inflow solids and physical features of the BMP) that might have led to the performance levels achieved. Finally, it also discusses other considerations that affect data transferability, such as effectiveness estimations, statistical testing, etc.

Introduction

Many studies have been completed which have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, stormwater wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings. However, in attempting to summarize the information gathered from these individual BMP evaluations it is very apparent that inconsistent study methods and reporting make wider scale assessments difficult. For example, individual studies often included the analysis of different constituents and utilized different methods for data collection and analysis. These differences alone contribute significantly to the range of BMP effectiveness reported. This makes assessing what other factors may have contributed to the variation in performance almost impossible.

In one review of the use of wetlands for stormwater pollution control (Strecker et al., 1992), a summary of the literature on performance of wetland systems and the factors that may have led to the reported pollutant removals was prepared. The literature was inconsistent with respect to the constituents analyzed and the methods used to gather and analyze data. A number of pieces of information, if collected and recorded, would have improved the ability to evaluate the effectiveness of stormwater wetlands as BMPs and facilitated the transfer of that knowledge into better design practices. Urbonas (1994 and 1995) and Strecker (1994) summarized the information that should be recorded about the physical, climatic, and geological parameters which likely affect the performance of a BMP, and considerations regarding sampling and analysis methods. This paper presents 1) a suggested list of constituents for analysis along with recommendations for reporting data, 2) methods of reporting pollutant removal efficiencies, 3) a brief discussion of statistical approaches to selecting the number of samples needed, 4) methods for including detection limit data, 5) sample collection considerations, and 6) the need for dry weather assessments.

BMP Performance Study Inconsistencies

Studies of BMP effectiveness have utilized significantly different:

- Sample collection techniques (e.g., from sample collection types (grab, composite, etc.), flow measurement techniques, to how the sample was composited, etc.);
- Constituents, including: chemical species, methods (detection limits), form (e.g., dissolved vs. total, vs. total recoverable, etc.), and treatment potential;
- Data reporting on tributary watershed and BMP design characteristics (e.g., tributary area or watershed attributes such as percent impervious, land use categories, rainfall statistics, etc.);
- Effectiveness estimation (at least four techniques have been utilized to assess effectiveness which can cause significant differences in pollutant removal reporting, with the same set of data), and potential alternatives to reporting just concentration/loading reductions; and
- Statistical validation of results (typical lack of statistical tests to determine if the reported removal efficiency

can in fact be shown to be statistically different than zero).

Any of the above topics would require an in-depth discussion beyond the scope of this paper to fully explain. Therefore, this paper will present a brief overview of each of these and some potential solutions to improving how data is collected. EPA together with ASCE is currently developing a set of protocols and a database on BMP performance studies with the purpose of improving the consistency of BMP monitoring information. This project includes:

- Developing Protocols for BMP Monitoring
- Conducting an evaluation of existing information to assist the EPA Wet Weather FACA and contribute to EPA's Stormwater Toolbox (as identified in Draft Phase II Stormwater Regulation Preamble)
- Developing a data base on BMP performance studies

The overall goal is to improve the BMP effectiveness information base to:

- Develop information to improve designs
- Improve performance information

The data base specifies a chosen set of reporting information, but does not tell how to develop such information. For example, it does not specify what a flow-weighted composite sample is and how it should be collected. The next step beyond the EPA protocols and data base effort should be a guidance document on monitoring data collection strategies and techniques to improve their consistency and transferability. It should be recognized that with the development of the database and the protocols, it will be a number of years (5 to 10) before significant new studies on BMPs are conducted utilizing the protocols to allow for a more rigorous evaluation of BMP selection and design factors.

Sample Collection Techniques

The differences among sample collection techniques alone is enough to make comparing different studies questionable. These include differences among how flows are measured to how samples are composited to formulate an "event mean concentration." Some studies have utilized grab samples, and the results of these studies in evaluating BMP performance are limited. Typically studies will include the collection of flow-weighted composite samples (either automated or hand collected). These studies involve various techniques (often not reported very well) for measuring flows. The flow measurements themselves are subject to a large variation.

The Federal Highway Administration is currently conducting a study of monitoring techniques for characterizing stormwater runoff hydrology and water quality from highways. The study, being completed by Woodward-Clyde, included a component conducted by the USGS (Waschbusch and Owens, 1998) which addressed the potential differences in flow measurement techniques in a pipe system in Madison, WI. An in-depth dye-dilution method was utilized to calibrate a Palmer-Bowlus flume with a bubbler pressure measurement. The study evaluated 23 flow measurement techniques including commercially available packages and individual component systems.

Figure 1 is a summary of the results of flow measurements, showing the average percent differences from the calibrated flume. These data summarize 50 storm events which were measured over a 6-month period. As the figure demonstrates, the error in flow measurements is easily on the order of plus or minus 25% over a range of storms. The flow measurements for individual storms varied even more. If samples are composited based upon flows (either using automated or using grab samples), they are subject to an error in collection times (for automated systems) or in composited amounts (grab sample composited) and therefore could result in errors in estimates of event mean concentrations (especially for constituents which vary over the course of a storm event). It should be strongly noted that these results are for one site only and should not be interpreted as indicative of how any particular system identified might perform at another site. It is imperative that researchers thoroughly evaluate potential flow measurement alternatives and implement the method that will result in the best information possible.

Another aspect of the study addressed how many samples should be collected to compile a "flow-weighted" composite sample. Figure 2 demonstrates the large variability in sampler bottle configurations. These configurations often drive researchers into selecting the number of "grab" composite samples to collect. For example, in the NPDES monitoring for Texas (Brush, et al., 1994), the chosen strategy was to collect one sample into each bottle of the 8-bottle configuration (this was successful if it rained sufficiently). In the Portland and Eugene NPDES Sampling (WCC 1993a and WCC 1993b), an attempt was made to collect 24 "grab" samples during the course of an event. Figure 3 shows a typical storm event from the Portland program and specifically the points at which a sample was collected. From the variability in flows observed, one can surmise the pollutant concentrations were also fluctuating extensively (later confirmed by within-storm sampling). Having only eight samples during this event may not have accurately characterized the event mean concentration (EMC). Collecting three times the samples to "construct" a flow-weighted sample would appear to reduce the chances of anomalies (variability) during a storm event influencing the overall estimate of the average concentration. Early results from our FHWA study indicate that one should attempt to collect at least 12 to 16 individual samples to form a composite sample.

The study also has evaluated the potential effects of sample lift (e.g. pumping up from underground or from stream bottoms) and has found that the newer samplers

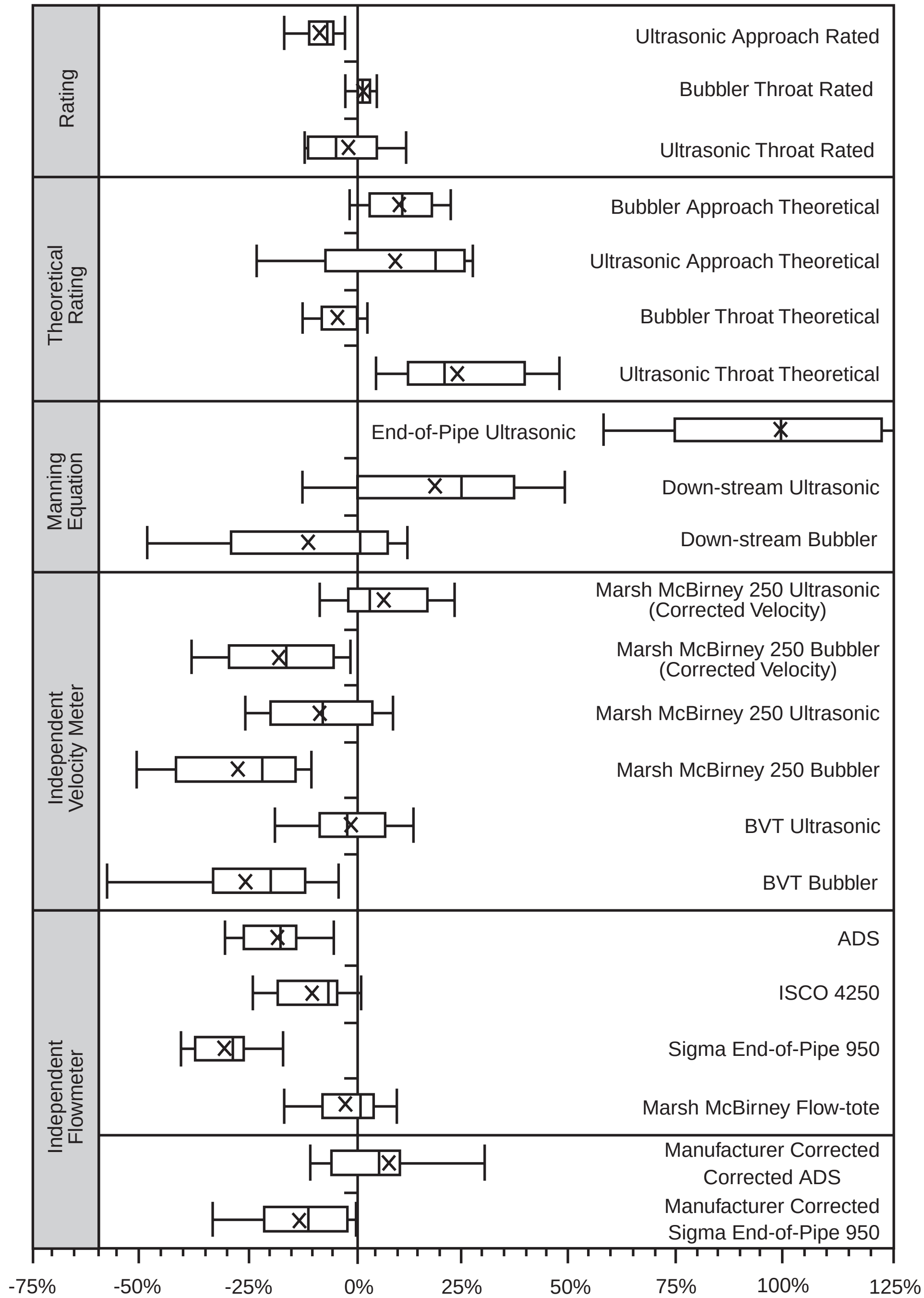


Figure 1. Boxplot of the percent differences between total storm volumes computed using various flow estimation methods and the total storm volume of the bubbler approach rated discharge (bold line at 0%). (Waschbusch and Owens, 1998).

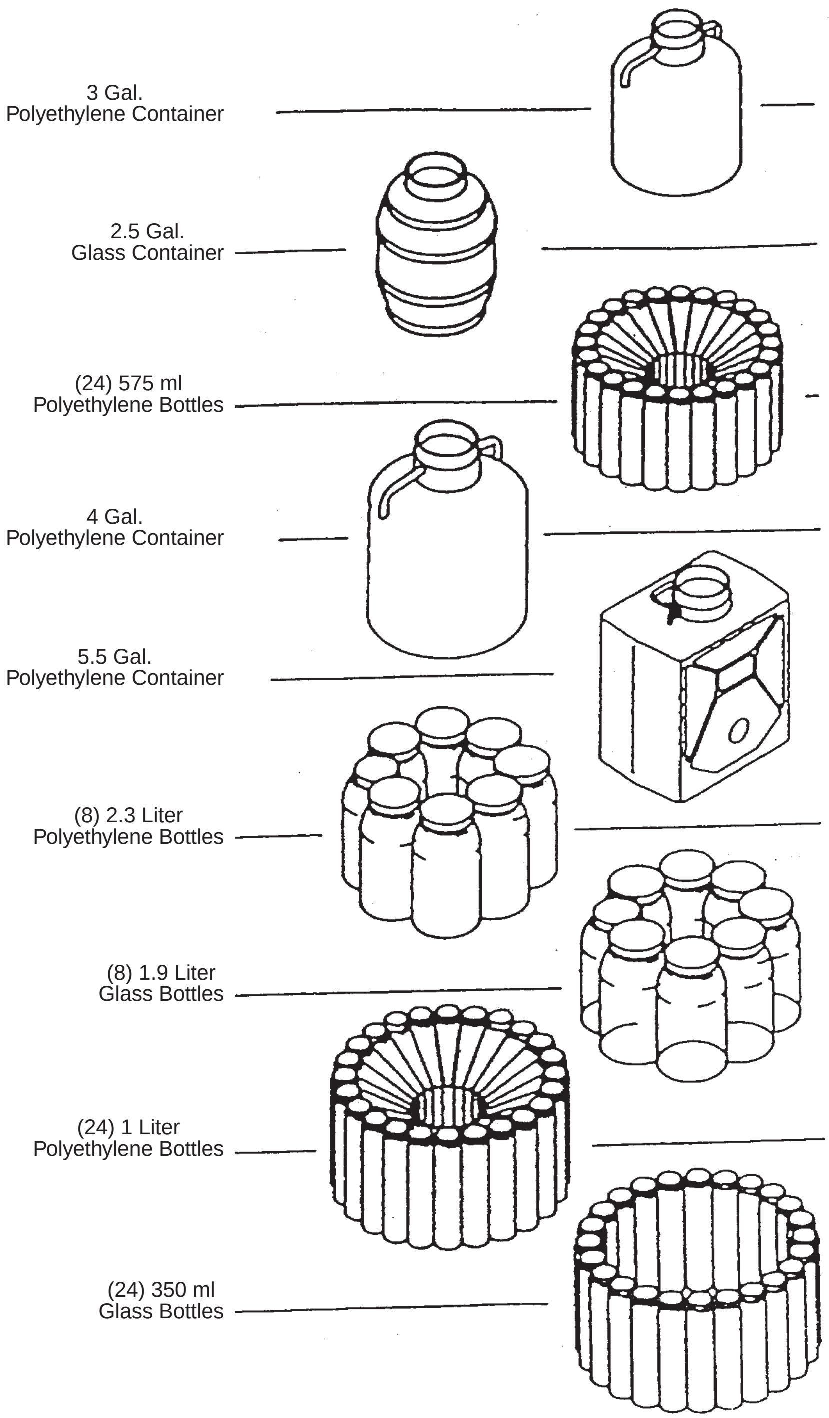


Figure 2. Typical automated sampling bottle configuration options.

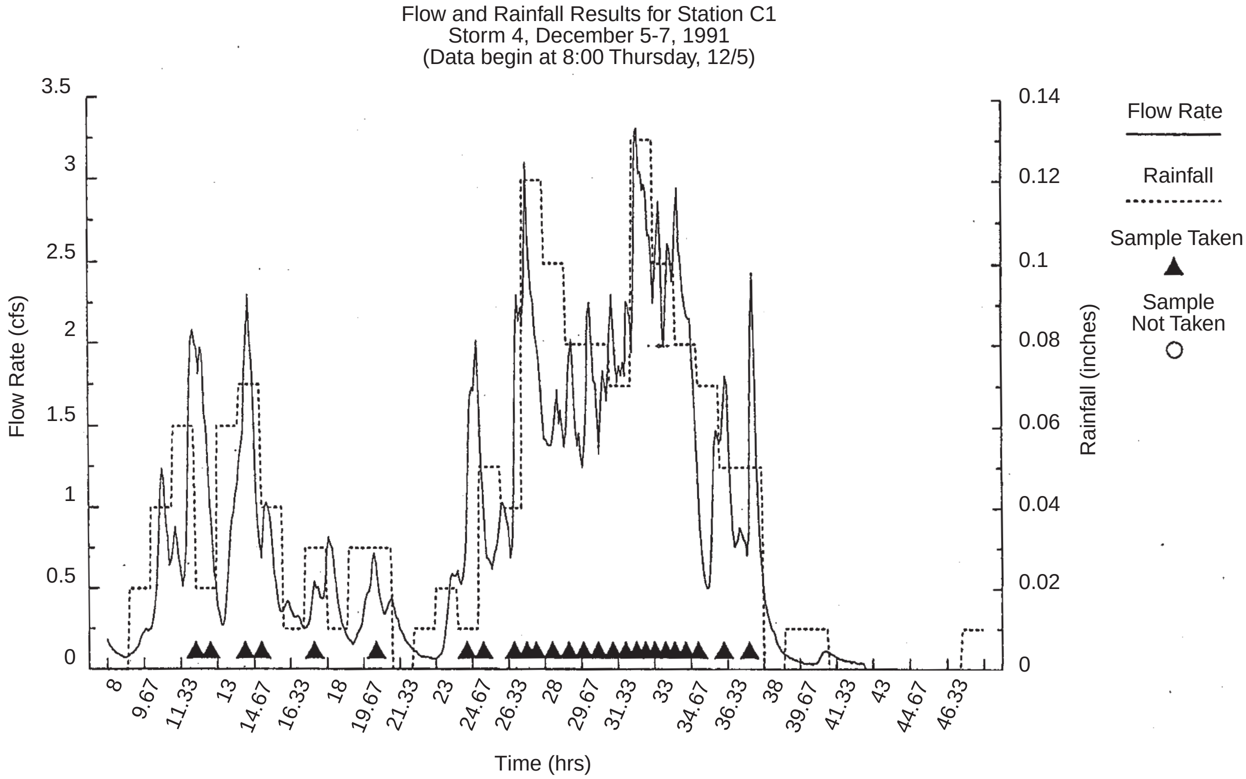


Figure 3. Typical hydrograph indicating measured rainfall, runoff, and water sample collection times from automated flow and water quality sampling for the Portland NPDES Stormwater Monitoring Program.

(with stronger pumps) do not appear to cause any separation of suspended solids as they are lifted up to 20 feet. At the end of the study, a guidance document on sampling of highway runoff will be developed. These are just some of the numerous differences in sampling methods that could lead to differences in results between BMP studies.

Constituents Assessed

A very wide variety of pollutants have been analyzed in both BMP studies and characterizations studies. The EPA protocols study has developed a recommended set of constituents for BMP testing programs. These were developed from the review of previous studies and an understanding of costs and likelihood of providing meaningful results. Below is a discussion of how these constituents were selected (adapted from Strecker, 1994).

Since NURP and prior to the Phase I Stormwater NPDES monitoring programs, there have been a number of studies which continued to assess pollutant concentrations in stormwater runoff. These included the Federal Highway Administration's highway runoff program (Driscoll et al., 1990) and some selected studies done in a few locations. These studies typically were not consistent with the standard NURP protocols. Based upon the 1987 amendments to the Clean Water Act, EPA required operators of municipal separate storm drainage systems that served populations of over 100,000 to collect flow-weighted composites at a minimum of five stations to characterize residential, commercial, and industrial runoff quality. Only a few additional parameters have been identified as "problems" in stormwater, based upon these post-NURP studies (this despite the improved analytical methods that have become available for conducting laboratory analyses). In addition, NURP focused primarily on residential and commercial land uses, while NPDES testing included industrial land uses which were suspected of having more pollutants present.

However, there has not been a comprehensive review by EPA or others of the newly collected stormwater information to assess the results of requiring the analysis of over 130 constituents, including priority pollutants. This type of review is needed. EPA's requirements included monitoring three storms at selected stations. This number of storms is only useful for identifying potential problem pollutants. Statistically, these are not enough data to perform a meaningful regional or other factor analyses of urban stormwater concentrations, although they could provide useful information on rates of detection. This analysis would be helpful in selecting constituents for BMP monitoring.

The choice of constituents to include as "standard pollutants" is a subjective one. As an example, some would argue that cost should be a primary consideration; others would say that it should not. In making the recommended list of monitoring constituents, the following characteristics were considered:

- The pollutant is prevalent in typical urban stormwater at concentrations that could cause water quality impairment.
- The analytical test can be related back to potential water quality impairment.
- Sampling methods for the pollutant are straightforward and reliable for a moderately careful investigator.
- Analysis of the pollutant is economical on a widespread basis.
- The pollutant is one for which treatment is a viable option.

Not all of the pollutants recommended fully meet all of the factors listed above; however, the factors were considered in the recommendations. When developing a list of pollutant analyses for an individual BMP evaluation, it is important to consider the upstream land use activities. The parameters recommended below are present and of concern in "typical" urban stormwater.

The Nationwide Urban Runoff Program (NURP) (EPA, 1983), which included monitoring of land use runoff and BMP performance at over 28 cities nationwide, adopted consistent data collection methods and analytical parameters. Results from the NURP program could be used to evaluate similarities and differences in pollutant concentrations in urban stormwater from different and similar land uses, and could be used to explain what might be causing these differences. The following pollutants were adopted by NURP as "standard pollutants characterizing urban runoff":

TSS	Total suspended solids
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TP	Total Phosphorus
SP	Soluble phosphorus
TKN	Total Kjeldahl nitrogen (as N)
$NO_2 + NO_3$	Nitrate + nitrite (as N)
CU	Copper
PB	Lead
ZN	Zinc

Oil and grease was not included because of the difficulty in obtaining representative samples. On a less consistent basis, NURP also monitored for pollutants including other metals, dissolved metals, semi-volatile organics, volatile organics, pesticides, and herbicides.

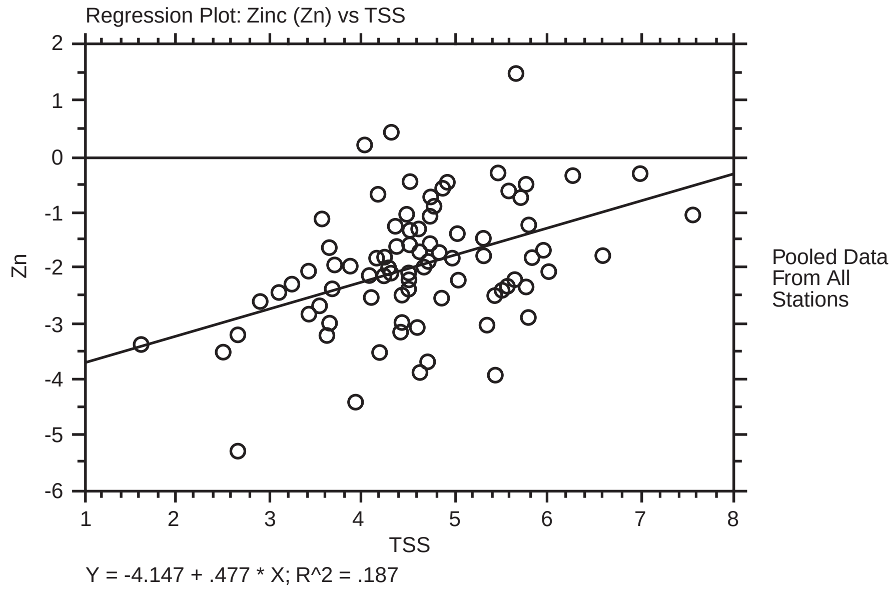
Presented below is a brief discussion, by group, of the pollutants that are recommended to be included in a base list, then several that may occasionally be recommended.

Total Suspended Solids (TSS). The term "suspended solids" is descriptive of the organic and inorganic particulate matter which is of a size and type that allows the particles to stay suspended in water. The solids load in a waterbody is influenced by a number of factors including but not limited to: particle sizes, stream flows, climate, geology, and vegetation of each drainage system. The conditions under which suspended solids are considered a pollutant is a matter of definition. In general, suspended solids are considered a pollutant when they significantly exceed natural concentrations and have a detrimental effect on water quality and/or beneficial uses of the water body.

Suspended sediments are often used as a surrogate for other contaminants which bind or adsorb easily with fine particulate matter, including heavy metals. Although TSS is often highly correlated with other parameters, it is generally not a strong enough correlation to eliminate the need to address other parameters specifically. Figure 4 shows the relationship between TSS and zinc for pooled stormwater runoff monitoring data from all ten stations monitored in Portland, Oregon for the NPDES program (WCC, 1993a) and from the seven stations that were from piped systems. Although the relationship is statistically significant (R^2 of .38 for piped stations), it does not explain a significant amount of the variability. Similar results were found for almost all other parameters. It should be noted that for individual stations, the relationships between TSS and many pollutants were sometimes much higher, but this would mean that one would have to monitor enough times to establish the relationship. Therefore, TSS does not appear to be a good predictor of other pollutants, without significant data collected from each station. However, TSS is one good indicator of pollutant removal efficiency (e.g., because of the tendency for many pollutants to be associated with fine particulates) and should be included in any evaluation of BMP performance.

Many BMPs rely on sedimentation as the primary pollutant removal mechanism. It is recommended that samples also be analyzed for some measure of the expected settling rate (treatment potential) of TSS. The performance of a BMP that relies on sedimentation and even filtering can be greatly affected by the particle sizes and densities present in the influent. If the influent TSS is characterized by very small particle sizes, and therefore slow settling velocities, it will be much more difficult to treat. The settleability of influent solids has not been adequately addressed in performance comparisons, and may be one of the significant reasons that measured performance varies so highly from similar BMP to BMP.

For consideration, the particle size distribution in street dirt found in Sartor and Boyd (1972), as shown in Table 1,



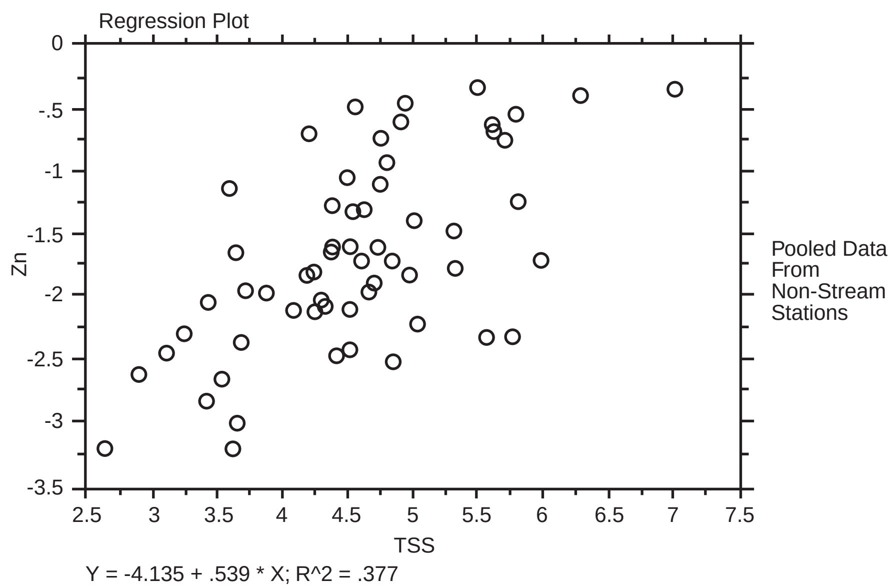


Figure 4. Natural logarithm regression plots of zinc (Zn as ln(mg/l)) vs. total suspended solids (TSS) for pooled Portland, OR stormwater monitoring event mean concentration data. (Woodward-Clyde Consultants, 1993a)

might be an appropriate gauge of the "treatment potential" of stormwater. As Table 1 indicates, these distributions vary considerably from city to city and likely from site to site. One can easily surmise that if testing were performed on similar catchments and BMP designs, that there could be a large difference in BMP performance results from these sites just due to the particle size differences alone. Another potential measure of the treatment potential would be information from settling column tests as those discussed by EPA in its manual on combined sewer overflow control (EPA, 1993a).

Oxygen Demand. Oxygen demand refers to the amount of oxygen that will be consumed by biological or chemical reactions involving organic compounds. The decomposition of biodegradable materials by natural soil and water bacteria draws upon the dissolved oxygen resources of a water body. This process is countered by natural re-aeration processes that occur in all water bodies to varying degrees. Significant reductions in dissolved oxygen concentrations can result when the demand rate exceeds the rate of replenishment through re-aeration. In general, moderately high dissolved oxygen content is necessary for the maintenance of healthy aquatic ecosystems. The relationship of oxygen-consuming discharges to the amount of dissolved oxygen in a receiving water body, therefore, is fundamental to the maintenance of environmental quality in natural water bodies. However, the tests available for

Table 1. Particle Size Fractions of Street Dirt from Selected Locations.

Size Ranges	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa
>4800 µ	12.0%	–%	17.4%	–%	–%
2000 - 4800 µ	12.1	10.1	4.6	14.8	37.1
840 - 2000 µ	40.8	7.3	6.0	6.6	9.4
246 - 840 µ	20.4	20.9	22.3	30.9	16.7
104 - 246 µ	5.5	15.5	20.3	29.5	17.1
43 - 104 µ	1.3	20.3	11.5	10.1	12.0
30 - 43 µ	4.2	13.3	10.1	5.1	3.7
14 - 30 µ	2.0	7.9	4.4	1.8	3.0
4 - 14 µ	1.2	4.7	2.6	0.9	0.9
>4 µ	0.5	–	0.9	0.3	0.1
Sand %, 43 - 3800 µ	92.1	74.1	82.1	91.9	92.3
Silt %, 4 - 43 µ	7.4	25.9	17.1	7.8	7.6
Clay %, <4 µ	0.5	–	0.9	0.3	0.1

Note: µ = microns
Source: Sartor and Boyd, 1972

assessing oxygen demand are not straightforward indicators of potential problems.

Biochemical Oxygen Demand (BOD). The 5-day BOD test provides an indirect measure of the quantity of biologically degradable organic matter in water in terms of the amount of oxygen required by microorganisms to oxidize it to carbon dioxide and water. The BOD test is quite variable. A number of factors can affect results, including the quality of the seed culture utilized in the test. The BOD test can also be inhibited by toxicants in the sample, which may react differently once the runoff mixes with the receiving water. The levels of BOD that are normally found in urban stormwater are near detection limits for the BOD test. Therefore, they are subject to wide variation. Therefore BOD has not been recommended as a parameter. Instead, TOC (Total Organic Carbon) has been identified as a more consistent measure of available organic material, which could be contributing to oxygen demand.

Chemical Oxygen Demand (COD). The COD test provides a more rapid and consistent measure of oxygen demand than BOD tests. The consumption of oxygen from an introduced strongly oxidizing chemical agent is measured by this test. As a result, it typically measures appreciably higher levels of oxygen demand than will be produced by biological decomposition because it oxidizes some organic compounds that are not biodegradable, and may also react with inorganic compounds as well. In urban stormwater, for example, COD levels are typically found to be about 8 to 10 times greater than BOD levels. COD measures a “maximum possible,” but not probable, oxygen demand.

Nutrients. Nutrients are necessary for the growth and support of biota in natural water systems. Excessive quantities can result in the over-stimulation of biological growth and the creation of objectionable water quality conditions (eutrophication). Some forms of nutrients can also be toxic (e.g., ammonia). In general, the most important nutrient factors causing an acceleration in algal production are nitrogen compounds and phosphorus.

Nitrogen. Nonpoint sources of nitrogen include lawn fertilizers, leachate from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitrite discharges from automobile exhausts and other combustion processes, natural sources such as mineralization of soil organic matter, and farm-site fertilizers and animal wastes. Many water treatment methods have no significant effect on nitrate removal from water (Dunne and Leopold, 1978).

Three forms of nitrogen have been analyzed extensively in stormwater runoff water quality studies. These are nitrite plus nitrate (NO_2 + NO_3), ammonia nitrogen (NH_3), and total Kjeldahl nitrogen (TKN). The latter, named after the analytical test procedure, provides a measure of ammonia and organic nitrogen forms that are present. The first (NO_2 + NO_3) provides a measure of the inorganic nitrogen. There is usually very little nitrite in stormwater. Nitrate (NO_3) is very mobile and is usually difficult to treat utilizing stormwater BMPs. Ammonia nitrogen can be toxic to aquatic life. It can be assessed for toxicity to aquatic life with data on pH and temperature. The inorganic (NO_2 + NO_3) and ammonia nitrogen are recommended. All forms should be reported as mass of nitrogen (N).

Phosphorus. Phosphorus is used by algae and higher aquatic plants and may be stored in excess of use within plant cells. With decomposition of plant cells, some phosphorus may be released immediately through bacterial action for recycling within the biotic community, while the remainder may be deposited with sediments.

Phosphorus enters waterways from many of the same sources as nitrogen. Domestic sewage contains significant concentrations of phosphorus which are contributed by detergents and human wastes. Primary and secondary treatment processes normally remove only about 20 to 30% of this element from sewage (Dunne and Leopold, 1978). Fertilizers and the erosion of soils rich in phosphorus can also be a potential source.

Three forms of phosphorus have been somewhat routinely analyzed in stormwater runoff studies. These include total phosphorus (TP), soluble phosphorus (SP), and ortho-phosphate (OP). Ortho-phosphate indicates the phosphorus that is most immediately biologically available. Soluble phosphorus includes both the ortho-phosphate and a fraction of the organic phosphorus. Most all of the SP is usually OP, however. Total phosphorus includes phosphorus in the forms that may not be as readily biologically available plus the forms discussed above. TP and OP are recommended for inclusion in a monitoring program, as they characterize both the total and bioavailable forms of phosphorus. All forms should be reported as mass of phosphorus (P).

Metals. Heavy metals such as copper, lead, and zinc are naturally released in very small quantities by the weathering of exposed soils and mineral deposits, corroding metal surfaces, decomposing paints, and certain corrosion-control compounds. Heavy metals tend to have comparatively low solubilities and are often mobilized by forming soluble complexes with humic materials or by becoming attached to clay particles. Heavy metals have been consistently identified as the most significant toxics found in urban stormwater and often exceed water quality criteria for aquatic life.

These metals are present in the biosphere as trace elements and are micronutrients necessary for plant and animal growth. Heavy metals are of concern because elevated concentration levels of soluble forms in natural water bodies can produce toxic effects in biota. Sources include domestic and industrial point-source discharges, urban stormwater runoff, and direct atmospheric deposition. In this paper, copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd) have been recommended for inclusion in a monitoring program because stormwater runoff water quality studies conducted at many urban locations have indicated that these metals are almost always present, and are at concentrations which tend to be elevated, relative to other heavy metals. They also can be used as surrogates for other heavy metals, as they tend to display the range of transport characteristics for heavy metals. However, other heavy metals should be analyzed if there are known sources of significant quantities of these metals in influent flows.

It is recommended that both the total and dissolved form of each be analyzed. Based upon EPA's recommendation, the dissolved fraction should be compared to water quality criteria, with modifications to the criteria as noted in EPA (1993b). To compare data to criteria, hardness should be measured for each sample. Too often, metals data are compared to criteria using an average hardness value not directly associated with the monitoring, and not associated with storm events. In the Williamatte Valley of Oregon, stormwater sampling has shown that hardness values during storm events are quite low, which results in low criteria values.

Total concentrations are valuable in assessing the overall reduction of the heavy metal in both soluble and particulate forms. There is a concern about the long-term bioavailability of these metals in sediments and sediment standards are beginning to be developed and implemented.

When conducting these tests, it is recommended that low detection limits be achieved. For copper, lead, and zinc, the detection limit should be 1 µg/l and for cadmium 0.2 µg/l. This will minimize problems with analyses that include below detection limit data, which can severely impact performance evaluations. Special "clean" procedures will be necessary to achieve low detection limits, both in the laboratory and in the field.

Too often, BMP effectiveness for metals is estimated based upon data that is very near or below detection. This is troublesome when both the inflow and outflow concentrations are at or near detection, and effectiveness is based upon a storm-by-storm comparison of loads or concentrations. It is recommended that if both the influent and effluent concentration are within five times the method detection limit, the pollutant data pair not be considered in the effectiveness analysis if a storm-by-storm method is used. If statistical characterizations of the inflow and the outflow concentrations are utilized to assess effectiveness and some of the data are below detection, appropriate techniques should be utilized. Driscoll et al. (1990) describes a method to address detection limit data. The setting of below-detection values to 0 or 1/2 the detection limit or the detection limit, will typically lead to an underestimation of the mean.

Oil and Grease. Oil and grease is a prevalent constituent in urban runoff and often exceeds discharge limits set by states (such as 10 mg/l in Oregon for industrial stormwater permits). In a study of oil and grease concentrations in urban runoff in Richmond, California, Stenstrom et al. (1984) found that oil and grease concentrations in runoff from commercial properties and parking lots are about three times higher than from residential and open areas. The NURP program did not address oil and grease as a standard constituent. Accurately measuring oil and grease is very difficult due to its affinity for coating sampling bottles and sampling tubes and its highly non-uniform distribution in the water column (except in the most turbulent situations). Other tests include total petroleum hydrocarbons, which measure the petroleum based fraction of oil and grease. Other sources of oil and grease include animal and vegetable. For BMPs which are designed to address oil and grease, it is suggested that some multiple, within a storm, grab sample analyses would be appropriate. For most BMPs, it is recommended that the parameter be optional. If completed, the TPH evaluation is recommended as the most appropriate measure to gauge effectiveness of a BMP at reducing man-induced sources of petroleum oil and greases.

Pesticides/Herbicides. Pesticides and herbicides are regularly detected in urban runoff. However, the number of constituents usually detected is low and most often at levels below available criteria. In Portland, Oregon (WCC, 1993a) the frequency of detection of pesticides herbicides was less than 1% of all the pesticides and herbicides tested. However, the city has noted locations where pesticide concentrations in sediments are high. This could indicate that the problem might be due to misuse or dumping, rather than a general stormwater problem. Although it is possible that pesticides accumulate in sediments from low concentrations in stormwater, some regional assessments of the effectiveness of source control measures (education, identification and elimination of dumping problems) are needed. The Alameda County, CA monitoring program (Cooke and Lee, 1993) and other studies have recently identified that the pesticide Diazinon may be a primary cause of toxicity at very low concentrations (below 8140 method detection limits) to *cerodaphrin dubia* in receiving streams in the south bay area of San Francisco. More research is needed to further define the level of this problem in relation to the actual instream biota, rather than test organisms. At this time, I would not recommend including the pesticide in a standard list, but research studies on the magnitude of the problem and the effectiveness of BMPs on these pesticides should be performed. Due to the low values at which these constituents can cause problems, it would be very difficult to assess BMP performance on a wide-scale basis. For example, it may be more appropriate to eliminate or control the use of Diazinon rather than research BMP effectiveness on concentrations that are below 1 ppb.

Volatile and Semi-Volatile Organics. These pollutants have not generally been detected at a high frequency and in quantities that exceed available criteria [with the exception of Polynuclear Aromatic Hydrocarbons (PAHs), which are discussed separately]. In the recent City of Portland and Eugene sampling programs (WCC, 1993a and 1993b) detection rates were less than 2% of all the tested constituents and below all available criteria. These parameters are not recommended for general analysis unless a BMP effectiveness study is being conducted in an industrial area suspected or known to have elevated levels of organics.

Polynuclear Aromatic Hydrocarbons. The carcinogenic properties of PAHs have generated increased interest in the study of their sources, transport, fate, and aquatic toxicity. Major sources include the combustion of fossil fuels, uncombusted petroleum products (fuels, etc.), and natural and man-caused fires. PAHs have recently been analyzed utilizing detection levels that are significantly below those achieved utilizing the standard semi-volatile organic scans (WCC, 1993a and 1993b; Cooke and Lee, 1993). These tests (GC-MS methods at the nanogram per liter level) have shown that PAHs in stormwater are above human consumption criteria by significant amounts (up to over 100 times). However, these tests are specialized (only a few laboratories provide this level of analysis) and expensive (about $500 to $600 per analysis). In addition, there are no criteria for aquatic life, and toxicity identification evaluations performed in the San Francisco Bay Area have not identified PAHs as the source of toxicity in either developed land-use runoff or in stream stations. For these reasons, PAHs are not recommended for the standard list of constituents to be monitored. However, because of their carcinogenic nature and their tendency to bioaccumulate, new studies may identify potential long-term aquatic life impacts that may require reevaluation of this recommendation.

Data Reporting

Practical and technical data reporting considerations, including consistent formatting of data, the clear indication of QA/QC results, standard comparisons to water quality criteria, reporting of tributary watershed characteristics, and BMP design information would facilitate data usefulness. The last two items are considered critical for evaluation of what contributed to BMP effectiveness in one location over another.

Data Formatting. It is recommended that all constituent concentration data be reported as event mean concentrations (EMCs). Table 2 is an example format for reporting storm event EMCs. It indicates the date of the storm, the EMC value for each sampling point, the data that are estimates based upon QA/QC evaluations, method used for analysis, and detection limit achieved. Also included are summary statistics of the EMCs. These statistics should be based on use of the lognormal distribution. The NURP and FHWA studies (EPA, 1983; Driscoll et al., 1983) identified the lognormal distribution as suitable for characterizing EMC distributions. An example of the variability in data is shown in Figure 5. The figure shows a log-probability plot for total copper collected at a commercial land use station. The event mean concentrations ranged from 6 to 70 μg/l. This high degree of variability is why proper statistical techniques should be employed to evaluate whether a measured difference between BMP before/after or input/output is truly different.

The inclusion of outlet data as a part of any paper or report will allow comparisons of typical outlet concentrations and may allow the determination of the lowest or average expected concentration from a particular type of BMP. For example, it may be that wet ponds may only be able to treat to some minimum concentration range at the outlet and the "effectiveness" is greatly impacted by the inlet concentrations.

Quality Assurance/Quality Control (QA/QC). All monitoring studies should include a QA/QC program. The results of the QA/QC program should be reported in monitoring study reports and summarized in papers. It is especially important to discuss when data are characterized as estimates due to QA/QC results and when detection limits were affected. Too often this information is not included.

Table 2. Example Data Reporting Table from Eugene NPDES Monitoring Summary Report (Woodward-Clyde Consultants, 1993b)

Chromium	(mg/L)			Method EPA 7191				Receiving Water Quality Criteria**
Storm Event	Date Sample	R-1	C-1	I-1	I-2	M-1	M-2	Detection Limit
#1	9/23/92	0.034	0.016	0.031	0.008		0.003	*0.001*
#2	12/5/92	0.005		0.005	0.003	0.001		*0.001*
#3	12/16/92	0.004	0.004	0.008	0.009		0.003	*0.001*
#4	1/19/93	0.004	0.012	0.019	0.011	0.008	0.004	*0.001*
#5	3/14/93	0.003	0.006	0.020	0.017	0.004	0.007	*0.001*
#6								
#7								
#8								
	Median	0.006	0.008	0.014	0.008	0.003	0.004	
	COV	1.27	0.70	0.86	0.71	–	0.42	
	Mean	0.010	0.010	0.018	0.010	–	0.004	

Copper	(mg/L)			Method EPA 6010				Receiving Water Quality Criteria**
Storm Event	Date Sample	R-1	C-1	I-1	I-2	M-1	M-2	Detection Limit
#1	9/23/92	0.081	0.130	0.071	0.016		0.019	0.001
#2	12/5/92	0.004		0.01	0.01	0.009		0.001
#3	12/16/92	0.011	0.016	0.037	0.03		0.009	0.004
#4	1/19/93	0.009	0.046	0.076	0.034	0.027	0.012	0.003
#5	3/14/93	<0.030	0.027	0.034	0.025	0.020	<0.030	0.004
#6								
#7								
#8								
	Median	0.012	0.040	0.037	0.021	0.017	0.013	
	COV	2.03	1.11	0.97	0.54	–	–	
	Mean	0.030	0.060	0.051	0.024	–	–	

Results expressed as mg/L (ppm) unless otherwise noted. COV is the Coefficient of Variation. ** Criteria are hardness dependent.
"nd" means none detected at or above the detection limit listed. If no value is shown, the lab analysis was not performed.
Summary statistics are based on the assumption that the samples of EMCs are lognormally distributed.
Italicized values are considered estimates due to QA/QC review but are included in the calculations.

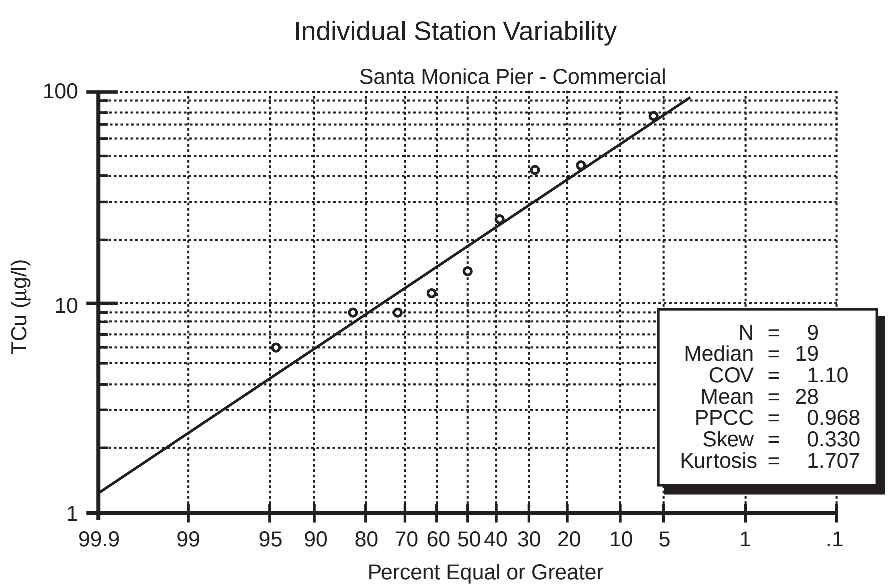


Figure 5. Example log probability plot of storm event mean concentrations from data collected by the Los Angeles County Stormwater Monitoring Program at the Santa Monica Pier (Santa Monica, CA) Commercial Land Use Station.

Comparisons to Water Quality Criteria. Another method to gauge effectiveness could be to monitor how the BMP effects the number of times that criteria are exceeded in both the inflow and the outflow, to assess how the BMP reduces (or does not reduce) the frequency of storm events where water quality criteria are exceeded. For heavy metals analyses, it is recommended that hardness be collected for all storms monitored and that comparisons to criteria be made utilizing the dissolved fraction with the computed aquatic criteria as modified by EPA (1993b). Figure 6 presents an example presentation of metals exceedances for data collected in Portland, OR (WCC 1993a). These data could be compared to BMP data for exceedances to determine whether or not a BMP was actually reducing potential toxicity.

Watershed BMP Design Parameters. Urbonas (1995) described information that should be collected regarding the physical, climatic, and geologic parameters, which include watershed and BMP design characteristics that could likely affect the performance of a BMP. Table 3 (Strecker and Urbonas, 1995) presents a summary of these parameters. More detailed and updated lists will be published upon completion of the EPA study referenced earlier.

Estimation of Pollutant Removal Effectiveness

BMP pollutant removal effectiveness estimations are not straightforward and a wide variety of methods have been employed. Martin and Smoot (1986) discussed the following three types of methods to compute efficiencies:

- The first method employs an efficiency ratio (ER), which is defined in terms of the average event mean concentration (EMC) of pollutants from inflows and outflows, thus:

$$ER = 1 - \frac{\text{Average outlet EMC}}{\text{Average inlet EMC}}$$

- The second method is based on the summation of loads (SOL) of pollutants removed during the monitored storms, thus:

$$SOL = 1 - \frac{\text{Sum of outlet loads}}{\text{Sum of inlet loads}}$$

- The third method of determining efficiency, developed by Martin and Smoot (1986), defines the ratio as the slope of a simple linear regression of inlet loads and outlet loads of pollutants. The equation for the regression of loads (ROL) efficiency is thus:

$$\text{Loads in} = ß \cdot \text{Loads out}$$

where ß equals the slope of the regression line, with the intercept constrained at zero.

The ER and SOL methods assume that monitored storms include samples representative of all storms that occur. The SOL method assumes that enough samples were collected so that any significant input loads or output loads were not missed. They are different in that one gauges effectiveness in terms of concentration reduction, while the other gauges effectiveness in terms of load of pollutant removed. The ROL method assumes that the treatment efficiency is the same for all storms, which is likely not the case.

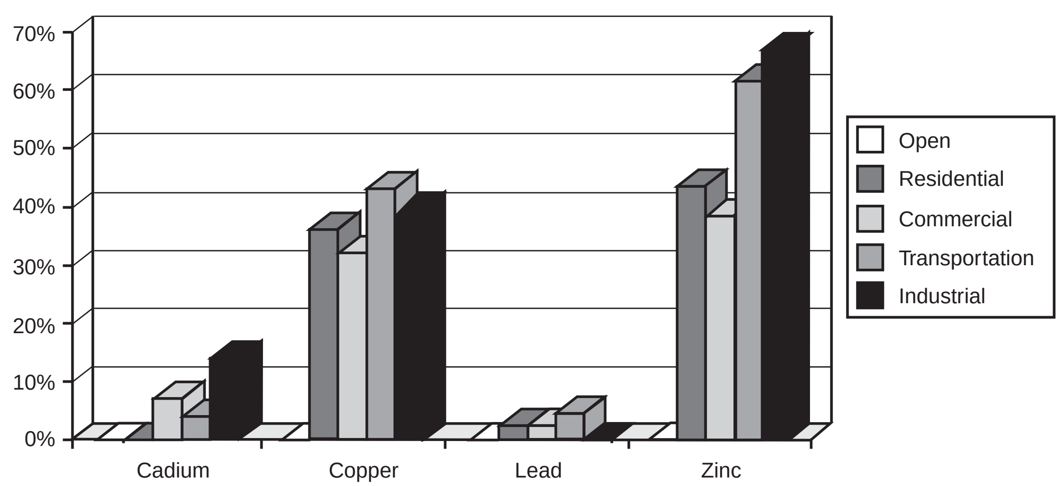


Figure 6. Frequency of water quality criteria exceedances of Oregon urban stormwater data collected for the Municipal Stormwater NPDES Programs.

Table 3. Parameters to Report with Water Quality Data for Various BMPs

Parameter Type	Parameter (1)	Retention (Wet) Pond (2)	Extended Detention Basin (3)	Wetland Pond Basin (4)	Grass/Swale Wetland Channel (5)	Sand/Leaf Compost Filter (6)	Oil & Sand Trap (Vault) (7)	Infiltration and Percolation (8)
Tributary Watershed	Tributary watershed area	•	•	•	•	•	•	•
	Total tributary watershed impervious percentage	•	•	•	•	•	•	•
	Percent of impervious area hyd. connected	•	•	•	•	•	•	•
	Gutter, sewer, swale, ditches in watershed?	•	•	•	•	•	•	•
	Land use types (res, comm, ind. open) and acreages	•	•	•	•	•	•	•
General Hydrology	Average storm runoff volume	•	•	•	•	•	•	•
	50th percentile storm runoff volume	•	•	•	•	•	•	•
	Coefficient of variation of runoff volumes	•	•	•	•	•	•	•
	Average daily base flow volume	•	•	•	•	•	•	•
	Average runoff interevent time	•	•	•	•	•	•	•
	50th percentile interevent time	•	•	•	•	•	•	•
	Coefficient of variation of interevent times	•	•	•	•	•	•	•
	Average storm duration	•	•	•	•	•	•	•
	50th percentile storm duration	•	•	•	•	•	•	•
	Coefficient of variation of storm durations	•	•	•	•	•	•	•
	2-year flood peak velocity				•		•	
	Depth high groundwater of impermeable layer		•	•				•
Water	Water temperature	•	•	•	•	•	•	•
	Alkalinity, hardness and pH	•	•	•	•	•	•	•
	Sediment setting velocity distribution, when available	•	•	•	•	•	•	•
	Facility on- or off-line?	•	•	•	•	•	•	•
	If off-line, amount of flow bypassed annually	•	•	•	•	•	•	•
General Facility	Type and frequency of maintenance	•	•	•	•	•	•	•
	Inlet and outlet dimensions and details	•	•	•	•	•	•	•
Wet Pool	Solar radiation, when available	•		•	•			
	Volume of permanent pool	•		•		•	•	
	Permanent pool surface area	•		•		•	•	
	Littoral zone surface area	•						
	Length of permanent pool	•		•		•	•	

(continued)

Table 3. Continued

Parameter Type	Parameter (1)	Retention (Wet) Pond (2)	Extended Detention Basin (3)	Wetland Pond Basin (4)	Grass/Swale Wetland Channel (5)	Sand/Leaf Compost Filter (6)	Oil & Sand Trap (Vault) (7)	Infiltration and Percolation (8)
Detention Volume	Detention (or surcharge) volume	•	•	•		•	•	•
	Detention basin's surface area	•	•	•		•	•	•
	Length of detention basin		•	•		•	•	•
	Brimfull emptying time	•	•	•		•	•	•
	Half-brimfull emptying time	•	•	•		•	•	•
	Bottom stage volume		•					
	Bottom stage surface area		•					
Pre-Treatment	Forebay volume	•	•	•		•	•	•
	Forebay length	•	•	•		•	•	•
	Other BMPs upstream?	•	•	•	•	•	•	•
Wetland Plant	Wetland type, rock filter present?			•	•			
	Percent of wetland surface at $P_{0.3}$ and $P_{0.6}$ depths			•	•			
	Meadow wetland surface area			•	•			
	Plant species and age of facility	•	•	•	•			

Adapted from Urbonas (1995)

Some researchers have suggested that one should utilize an efficiency measure based upon storm pollutant loads into and out of the BMP on a storm-by-storm basis. This would weight the effectiveness considering that all storms are "equal" in computing the average removal. However, it is readily apparent that all storm volumes and their associated concentrations are not equal. Similarly one could utilize concentrations on a storm-by-storm basis.

One factor that complicates the estimation of effectiveness is that, for wet ponds and wetlands (and other BMPs where there is a permanent pool), comparing effectiveness on a storm-by-storm basis neglects the fact that the outflow being measured may have a limited or no relationship to the inflow. In analysis of rain gauges utilizing SYNOP (Driscoll, et al., 1989), if a basin sized to have a permanent pool equal to the average storm, about 60 to 70% of the storms would be less than this volume. In many cases, the flows leaving may have little or no contribution to flows entering the pond. Therefore, storm-to-storm comparisons are probably not valid. In cases like this, it is probably more appropriate to utilize statistical characterizations of the inflow and outflow concentrations to evaluate effectiveness or, if enough samples are collected (i.e., almost all storms monitored), to utilize total loads into and out of the BMP.

Using the same set of data, Table 4 compares three of the methods including percent removal by storm with a statistical characterization of inflow/outflow concentration and a simple comparison of total loads in and out for the sampled storms. As one can see, the removals estimated differ by up to 19 percentage points. In this record, there are several storm events where inflow concentrations were relatively low and therefore the system was not "effective".

Based upon these factors, it is recommended that the statistical characterization of inflows vs. outflows be utilized (ER). This enhances the ability to conduct statistical tests of whether the reported differences are greater than zero. If enough data on storms are collected (e.g. continuous samples over an extended period), the total loads in and out (SOL) is probably an acceptable method also.

BMP Evaluations – Statistical Considerations

As noted in many studies of urban runoff, the variability in runoff concentrations from event to event is large. If one were to attempt to statistically characterize a BMP influent concentration (and outflow), the more data the better, Figure 7 is a schematic of how more data can improve (reduce confidence interval of) results. As mentioned above, there are a number of types of BMP evaluations that can be conducted. First, the standard evaluation of a single BMP, testing input and output; second, the evaluation of multiple BMPs within a basin (before/after or control ba-

Table 4. Example Wetland TSS Removal

Storm	Volume of (ft^3) Inflow = Outflow	Concentration In (mg/L)	Concentration Out (mg/L)	Load In (lbs)	Load Out (lbs)		% Removal by storm
1	445,300	352	24	9780	670		93%
2	649,800	30	25	1220	1010		17
3	456,100	99	83	2820	2360		16
4	348,111	433	141	9410	3060		67
5	730,261	115	63	5240	2870		45
	Med	139	65			A	
	Cov	1.48	.86	28,470	9,970	V	48%
	Mean	249	85			G	
		Conc	66%	Loads	65%		

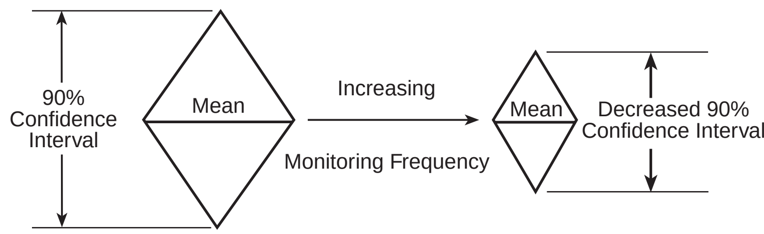


Figure 7. Expected change of 90% confidence interval of station mean with additional data.

sin); and finally a third, the evaluation of a BMP with multiple inlets (where it might be very difficult (expensive) to evaluate the BMP utilizing input/output). All methods should require that a rigorous statistical approach be applied in selecting the number of samples to be collected to assure detection of a given level of change.

As an example of the number of samples required to detect a “true” difference, Table 5 presents an analysis of two of the Portland NPDES monitoring stations (WCC, 1993a) where 10 flow-weighted composited samples were collected. The Fanno Creek station is a large (about 1,200 acres) residential catchment, while the M1 station is a smaller (about 100 acres) mixed land use station. An analysis of a variance-based test was utilized with the existing data to determine how many samples are estimated to be needed to detect a 5%, 20%, and 50% change in the mean concentration at the station. The test was performed considering an 80% probability that the difference will be found to be significant, with a 5% level of significance (Sokal and Rohlf, 1969). This analysis does not consider potential seasonal effects on the collection of data as a factor. Even so, quite a large number of samples would be required to detect a 5% to 20% difference in concentrations. Figure 8 shows a map of the US plotting the average number of storms per year (over 0.1”) as determined by EPA (Driscoll et al., 1989) occur. One can see that in many locations, it would take a number of years of sampling all storm events to be able to detect small differences.

There are numerous examples in the literature where small differences (2 to 5%) are reported based upon much fewer samples than indicated by this analysis. This highlights the need to be more rigorous with regard to statistical testing of reported effectiveness estimates. To detect larger changes, the number of samples becomes reasonable. The mixed land use catchment in Portland is currently being studied for the effectiveness of the implementation of a number of source controls and other controls that do not lend themselves to input/output testing. Examples include maintenance changes (catch basin cleaning, street sweeping), education (business and residences), tree planting, etc. Post-BMP monitoring will be conducted along with qualitative evaluations.

As an example that demonstrates how one could evaluate whether one catchment is different than another, Figure 9 presents results of analysis of stormwater monitoring data collected in Oregon. The figure presents a statistical characterization of land use data, demonstrating that for Total Copper, the open and residential land use stations are statistically different from all other land uses as well as from each other. A similar analysis technique should be employed for all before and after tests, as well as “control” tests.

Table 5. Analysis of Sample Sizes Needed to Statistically Detect Changes in Mean Pollutant Concentrations from 2 Stations in Portland, OR.

Monitoring Site	Parameter	Number of Samples Required to Detect the Indicated % Reduction in Site Mean Concentration* 5%	20%	50%
R1 - Fanno Creek Residential	TSS	202	14	4
	Copper	442	29	6
	Phosphorus	244	16	4
M1 - NE 122nd Columbia Slough Mixed Use	TSS	61	5	2
	Copper	226	15	4
	Phosphorus	105	8	3

*80% certain of detecting the indicated % reduction in mean of the EMCs.

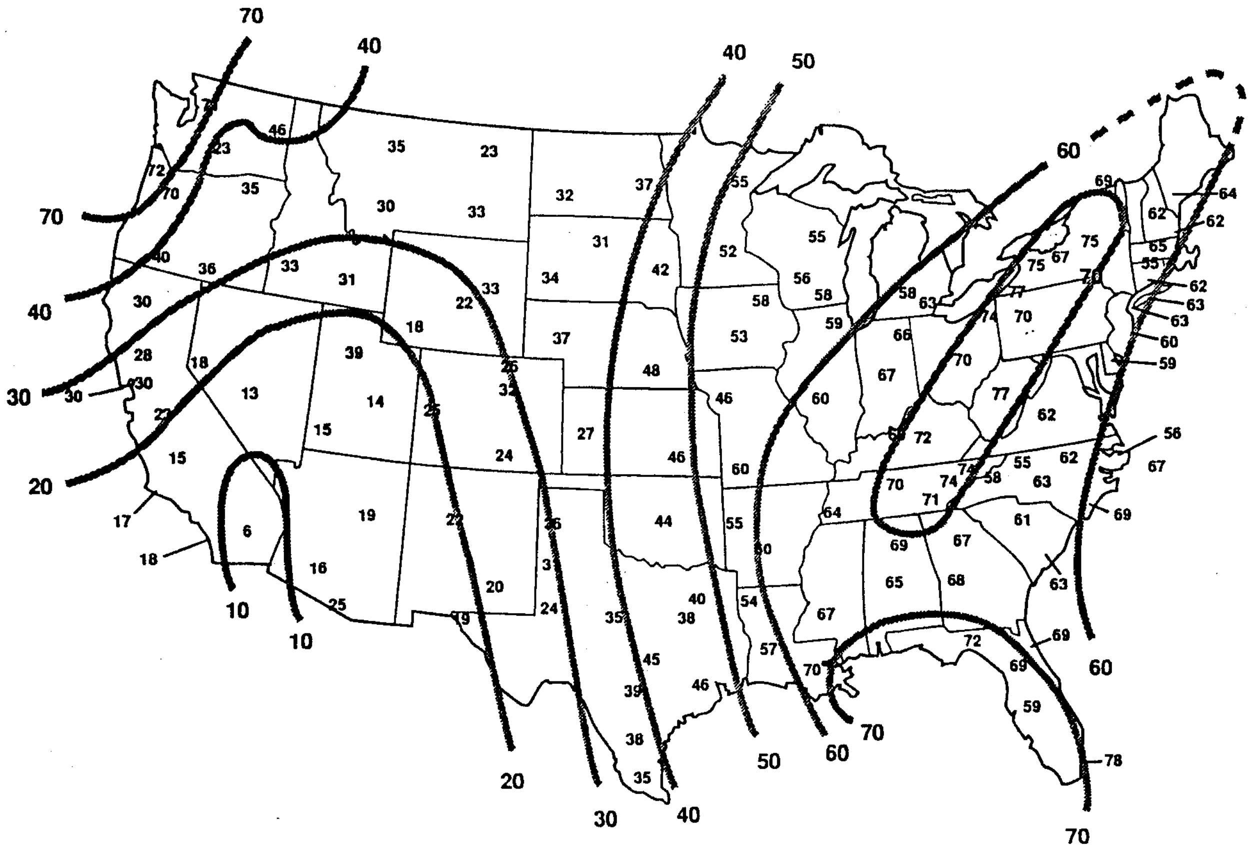


Figure 8. Annual average number of storms. (storms/year)

Other Considerations

There is a need to conduct dry weather analyses between storms on BMPs with dry weather flows; it may be that pollutants captured during storms are slowly released during dry weather discharges.

Biological and downstream physical habitat assessments such as aquatic invertebrate sampling and habitat classification should be explored as an alternative to merely utilizing chemical measures of effectiveness (see Maxted, these proceedings); long-term trends in receiving water quality, coupled with biological assessments, would likely be a much better gauge of the success of the implementation of BMPs, especially on an area-wide basis.

Summary and Recommendations

There is a great need for consistency in the constituents and methods utilized for assessing BMP effectiveness. This

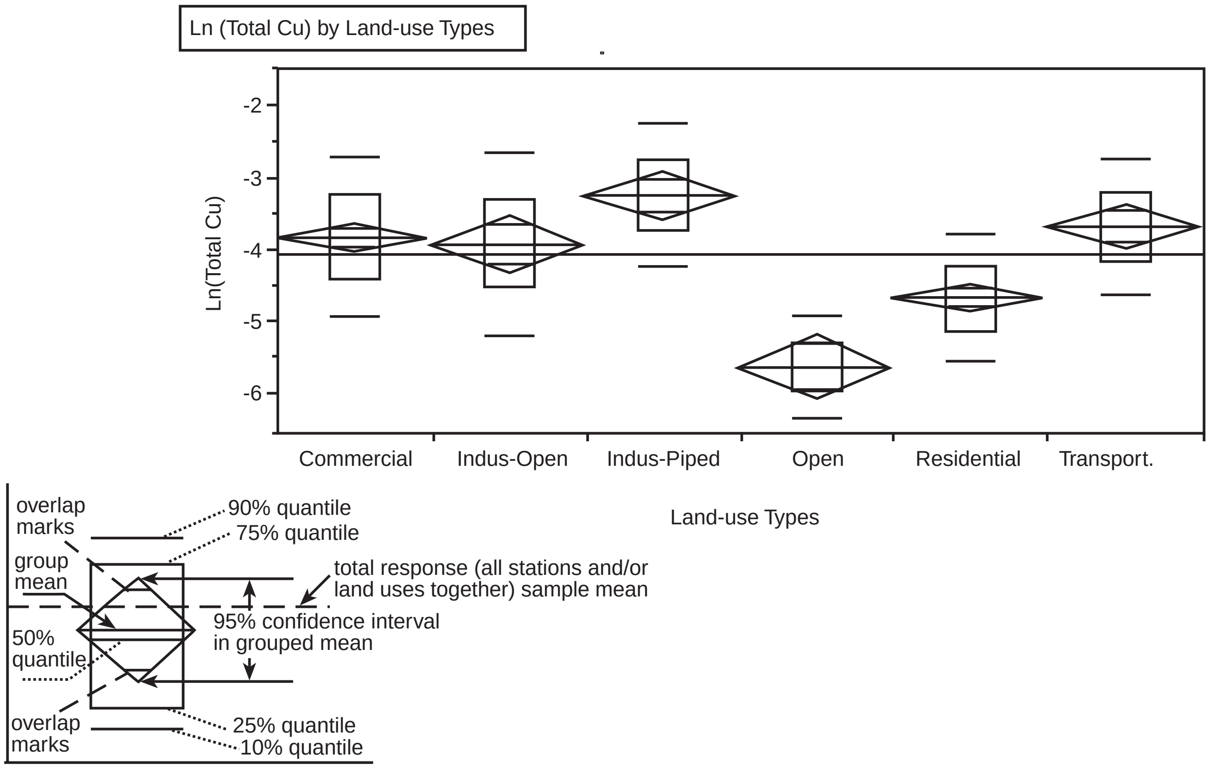


Figure 9. Box Plots of land-use event mean concentration for Oregon stormwater collected for the Municipal Stormwater NPDES Program. (Strecker, et al., 1997)

paper has presented only some of the consistency issues. It is recommended that researchers who undertake BMP effectiveness studies consider the recommendations suggested here, and by Urbonas (1995). It is the authors' opinion that EPA should require studies receiving federal funding to conduct BMP effectiveness studies which utilize standard methods (as suggested here) together with (still much needed) detailed guidance on data collection and sampling methods to improve data transferability.

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Targets of Opportunity: Alexandria's Urban Retrofit Program

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During 1992 preparations for a stormwater quality program as part of the Alexandria (Virginia) Chesapeake Bay Preservation Ordinance, the city engineering staff made a survey to identify opportunities for future urban BMP retrofitting. The objective of the current "Targets of Opportunity" program is to enhance the minimum requirements of the Virginia Chesapeake Bay Preservation Act (CBPA) program by providing treatment of stormwater runoff from built-up areas not directly addressed by the CBPA, in order to further reduce pollutants reaching the bay and its tributaries.

Since the inception of the Targets of Opportunity Program, almost 1,000 acres of urban BMP retrofits have been installed within Alexandria. A substantial part of Alexandria's urban retrofits have been voluntarily designed and constructed by developers of adjacent downhill properties. While comprising only 3.3% of the urbanized area within the Potomac and Shenandoah basin, the city has already contributed almost 23% of the total urban retrofit coverage proposed in the *Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy* (Commonwealth of Virginia, 1996.) Estimated nutrient reductions already exceed the urban retrofit phosphorus and nitrogen reduction targets contained in the Shenandoah Strategy, and are within 3% of meeting the nitrogen reduction target.

Characteristics of Alexandria

Alexandria is a city of approximately 115,000 citizens located on the Potomac River in Northern Virginia between Fairfax County and Arlington County. Founded in 1749 as a deep river seaport, the city is currently some 15.75 square miles in size. The population is diverse and relatively affluent, some 56,000 households with a median income of approximately $53,000. Directly across the Potomac from Washington, D.C., Alexandria's largest employer remains the federal government. However, extensive development during the past decade has resulted in a thriving commercial sector, with divisional, regional, and multinational headquarters for operations ranging from research and development to high technology, associations, and professional services now located in the city. With a 1990 population density of 7,281 people per square mile. Alexandria is the most densely developed city in Virginia and the eleventh most densely populated city in the United States. Approximately 41% of the total city area is covered with impervious surfaces.

Alexandria is a city bounded by and laced with streams. The eastern boundary is 5.6 miles of Potomac River shoreline. The northern boundary with Arlington County includes 1.9 miles of Four Mile Run, 100-year flood channel reconstructed by the U.S. Army Corps of Engineers in the 1970s following extensive flooding during Hurricane Agnes. A similar 1.7 miles of channel conveying Cameron Run borders the Capital Beltway, the southern border with Fairfax County. Approximately 8.4 miles of small tributary streams flow north or south into the boundary channels, approximately 20% to Four Mile Run, 20% directly into the Potomac River, and 60% into Cameron Run or its major tributaries, Backlick Run and Holmes Run. Almost all of Alexandria's streams except the Potomac River are severely degraded urban streams. Protection and partial restoration of these streams and the Chesapeake Bay into which they flow is the focus of the city's nonpoint source programs.

Governing Clean Water Programs

Alexandria's clean water programs are governed by several federal and state authorities. Initially, the city was classified as a medium-sized city under the National Pollution Discharge Elimination System (NPDES) Permit requirements for separate stormwater systems, requiring an MS4 permit. (The city was later reclassified as a small city based on population reductions allowed for regions served by permitted combined sewer systems). Virginia has also adopted a number of programs in support of the federal and multi-state Chesapeake Bay Program. The Virginia CBPA includes a mandatory program requiring provisions for stormwater quality on development projects within the bay watershed.

The Virginia Stormwater Management Act is a discretionary program which allows stormwater quality to be required of development projects throughout the commonwealth. The Virginia Erosion and Sediment Control Act requires stormwater quality measures during construction on all but very small development projects. The Chesapeake Bay Tributary Nutrient Strategies require nutrient reductions from all point and nonpoint sources to achieve 40% reductions in the Bay. These reductions to get nutrient levels below the 1985 baseline have been targeted for the year 2000 by the bay program signatories. Only the Tributary Strategies address the question of urban BMP (Best Management Practices) retrofits.

Tributary Targets

The Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy (the Strategy) defines urban BMP retrofits as "Modifying existing stormwater facilities to enhance water quality and/or retrofitting stormwater drainage systems to add water quality components in already developed areas to slow runoff, remove sediment and nutrients, and provide a basis for restoring eroded stream channels." The strategy sets a target of 4,356 acres of urban retrofit within the entire basin, of which 1,156 acres was in addition to that existing at the time of the printing. The Strategy lists total urbanized watershed as 454 square miles (290,400 acres), including Alexandria's 15.75 square miles (10,080 acres), approximately 3.5% of the watershed.

Targets of Opportunity Program

Stormwater Quality Program Adoption

Alexandria's initial stormwater quality program was its erosion and sediment control ordinance, which was adopted in the 1970s. In 1990, the city began an intensive effort to prepare an application for an NPDES permit for its stormwater program. Concurrently, city staff enacted a Chesapeake Bay Preservation Ordinance (City of Alexandria, 1991) which contains provisions from both the Chesapeake Bay Preservation Act and the Stormwater Management Act. City staff identified several sites where urban retrofits appeared possible. Staff members responsible for reviewing development proposals were directed to discuss the possibility of including urban retrofit as part of proposed developments. The objective of this program was to enhance the mandatory requirements of the Chesapeake Bay Preservation program with additional treatment of stormwater runoff from built-up areas not directly addressed by that act, to further reduce pollutants reaching the bay and its tributaries. The program was already in place and functioning when the Virginia Potomac Basin Tributary Nutrient Reduction Strategy was developed and adopted in 1995-1996 (Commonwealth of Virginia, 1996).

Elements of the Targets of Opportunity Program

There are four basic elements to the Targets of Opportunity Program. The first is knowledge of the watersheds within the jurisdiction. The Alexandria staff used aerial photographs, topographic maps, and the sewer outfall map prepared for the Part I NPDES Stormwater submission. Discussions with storm and sanitary sewer maintenance personnel with many years of experience in the city were also very valuable.

The second element is the identification of potential opportunities for urban retrofits. Sites in the watersheds of streams which receive large numbers of stormwater outfalls are especially desirable to maximize the effectiveness of retrofit BMPs. Alexandria also focused on areas with existing ponds and detention basins which could be adapted in the future for service as either regional retention basins (wet ponds) or extended detention basins (dry ponds).

The third element is one of the most crucial: early exploration of urban retrofit options with owners/developers. Alexandria's zoning ordinance requires a pre-submission conference with the city staff for all significant construction projects. This conference usually occurs prior to finalization of the stormwater concept plan for the respective site, allowing the staff an opportunity to discuss retrofit options with the development team. For smaller projects, the staff almost always becomes aware of proposed development well before formal submission through informal contacts with the engineering community.

Once contact is established, the fourth element comes into play: creating "win-win" situations for both the developers and the public. In some cases, developers may find it less expensive to treat the entire flow of existing storm sewers transiting a site rather than construct a separate "off-line" system to collect and treat stormwater runoff. Alternatively, construction (at the developer's expense) of regional facilities on public land may be more economically beneficial to a developer than construction on-site BMPs. Fostering a spirit of cooperation between the parties rather than an adversarial regulator/regulated relationship is crucial to obtaining results in a program of this nature.

Status of the Targets of Opportunity Program

Seven significant urban stormwater BMP retrofit projects have been approved under the Targets of Opportunity Program. A discussion of each of the projects illustrates how the various program elements were implemented.

Winkler Run Regional Retention Facility

The Mark Winkler Corporation, which owns a large development tract in western Alexandria, proposed to construct a combined stormwater detention/water quality pond system to stop a severe erosion problem and to provide detention and water quality for future buildout of their property. Noting that the watershed draining through the site included significant built-up areas, the staff discussed with the developer's engineer the possibility of sizing the pond to provide water quality for the entire watershed at full buildout under city zoning. The developer agreed and of the total watershed of 221 acres, 126.7 acres was urban retrofit. Estimated impervious cover on this acreage, which includes 26 acres of Interstate 395 and the heavily traveled Seminary Road and Beauregard Street, apartment houses, and hotel and office complexes, is 82.3%. The Winkler Run Pond System was built to a design from the

Washington Council of Governments manual, *Controlling Urban Runoff*, (Schueler, 1987) and is rated to provide 45% phosphorous removal. The system of two ponds in series was constructed in 1992. Based on information in the manual, city staff estimate total nitrogen removal at approximately 30% (see the Attachment for nutrient estimating methodology). At these ratings, the total yearly reductions from the urban retrofit areas are 397 pounds per year of phosphorus and 1,960 pounds per year of nitrogen. The system was constructed solely at the developer's expense.

Lake Cook Regional Retention Facility

The next significant urban retrofit involved a project to restore a viable habitat for aquatic life in Lake Cook, a recreational lake owned by the city and operated by the Northern Virginia Regional Park Authority (NVRPA). In 1993, NVRPA requested the city to restore sufficient depth to maintain for recreational fish in Lake Cook in the Cameron Run Regional Park. Originally four feet deep, the three-acre lake had silted until less than two feet of depth remained. During an earlier review of the outfall map, the engineering staff had noted that the lake was fed by Strawberry Run, a stream receiving the outfalls from over 30 storm sewers having a diameter of 36 inches or greater. The staff determined that if the lake were deepened to an average of six feet, the pool could serve as a regional wet pond BMP for approximately the 385 acres of fully developed watershed draining into the lake. A sediment forebay was also added to trap sediments at the upstream end of the lake, protecting the fish habitat and easing future maintenance.

The lake was deepened during the winter of 1993-1994. Only approximately 20% of the total project cost of $75,000 (funded by Alexandria general revenues) was attributable to the stormwater quality features. Based on the BMP phosphorus removal ratings currently proposed for inclusion within the Virginia Stormwater Management Regulations, Virginia Chesapeake Bay Protection Regulations, and the WASHCOG nitrogen removal estimates for such ponds, the staff estimates that the lake now removes approximately 926 pounds of phosphorus and 4,222 pounds of nitrogen per year from stormwater runoff entering Cameron Run.

Cameron Lake Regional Retention Facility

In the early 1990s, the Department of Defense decided to close the 164.5-acre Cameron Station Army Base in Alexandria and sell the land for private development. While developing future zoning of the property, city staff noted that two connected lakes on the station which would become a city park acted as stormwater detention ponds for approximately 60 acres of runoff. Total surface area of the lakes was almost 5 acres, and their permanent pools could be deepened to serve as a regional retention pond for a much larger area, including some of the most intensely developed areas of the city. Due to early coordination with the Army, the city was able to insert a condition that required all future development on the site to drain through the lakes. The condition also required city storm sewers which transited the base to be rerouted through the lakes. The purchaser of the base readily participated in this public-private partnership, recognizing that it would provide a win-win relationship.

By allowing the developer to retrofit the existing lakes, greater densities of development were created, which more than compensated for the cost of upgrading the retention facility. Additionally, if the developer had held the density of development as originally planned, a series of sand filters would have been needed to provide water quality for the 97.5 acres of development at a cost considerably higher than the retrofitting of the existing lakes. Recognizing that the regional facility would provide a win-win situation, the developer agreed to the incorporation of several state-of-the-art features into the retrofit.

Work began with draining the lake and removing approximately 20,000 cubic yards of material to create an appropriate permanent pool. The existing outlet structure, consisting of little more than a concrete flume with a wire trash rack, was removed and replaced with an upflow anaerobic trickling filter. Additional features include a sediment forebay which can be isolated from the permanent pool during maintenance and an oil skimmer to retain floating hydrocarbons, trash, etc., from reaching the main basin of the lake. Facilities to monitor flow rates through the pond and chemical composition of the flows were also provided. Constructed during the summer of 1997, the regional retention facility is treating runoff from 246.83 acres, 187 acres of which did not previously drain through the lakes. The entire drainage shed except for the 97.5 acres of development property is urban retrofit. Based on Virginia and WASHCOG BMP ratings, the staff estimates that, when full buildout of Cameron Station is completed, the facility will remove approximately 709 pounds of phosphorus per year and 3,235 pounds of nitrogen from stormwater runoff entering Backlick Run.

Park Center Regional Extended Detention Facility

Since 1992, the city staff has been recommending the conversion of a large 100-year storm detention facility in the western part of the city into a stormwater quality BMP. Early plans to convert it to a regional retention facility collapsed when one of the adjacent property owners objected to the presence of a permanent pool. However, in the fall of 1996, the owner of the basin submitted a development plan to construct new office towers adjacent to the basin. Rather than require construction of new BMPs for the 8.12-acre development, the city proposed to the developer's engineer that the basin be converted into a regional extended detention facility to serve a 245-acre watershed. An adequate dam and riser structure able to accommodate a 100-year storm was already in place; the conversion involved only modifications to the riser structure to provide a reduced orifice at the bottom of the dam and new overflow openings at the top of the new BMP detention pool. The entire expense of this construction, which is currently in progress, is being borne by the developer. Using the Virginia BMP rating of 35% for phosphorus reduction, the staff estimates that the 237 acres of urban retrofit is removing approximately 307 pounds of phosphorous from Lucky Run, a tributary of Four-Mile Run and the Potomac River. The staff is not currently convinced that significant nitrogen removal occurs in extended detention ponds.

Slater's Village Regional Extended Detention Facility

When a development with 145 townhouses and 128 condominium units was proposed in 1996 for part of the old Potomac Rail Yard at the northern portion of Alexandria, the developer's engineer observed that reinforced concrete storm sewer serving existing developments traversed the site. It was determined that it would be less expensive for the developer to construct an extended detention facility to treat all of the runoff conveyed by this sewer than to construct a completely separate storm sewer system and BMP to serve only the new townhouses. He therefore proposed to drain the new development directly into the storm sewer and treat the total runoff downstream of the townhouses. This provided an additional 38 acres of pure urban retrofit to the new extended detention facility. Using Virginia BMP ratings, the staff estimates that this urban retrofit removes an additional 75 pounds of phosphorus from runoff flowing directly into the Potomac River. The BMP was constructed as an erosion control basin in the summer of 1997 and will be converted to a full BMP upon completion of the construction project.

Episcopal Seminary Regional Retention Facility

The Episcopal Theological Seminary, a large landholder in central Alexandria, recently decided to construct a state-of-the-art stormwater retention facility to use as a teaching tool for environmental classes at the private high school on site. The pond, was also designed as a stormwater retrofit pond to serve existing development on the property to provide stormwater quality for any future expansion of facilities. The pond serves a 51-acre watershed with an ultimate runoff factor of 0.44. The city staff considers this private pond to be totally urban retrofit. Initial estimates suggest that this BMP will remove 128.5 pounds per year of phosphorus and 586 pounds per year of nitrogen currently reaching Cameron Run and the Potomac River.

Potomac Retail Center Urban Retrofit

When design began on a 60-acre shopping center to occupy part of a former rail yard in the northern part of Alexandria, the developer's engineer was required to deal with the runoff from 9.9 acres near U.S. Route 1 including adjacent properties which already drained through ditches in the rail yard. Rather than provide a separate conveyance for this off-site water, the engineer proposed to route it through a large retention pond being built to treat development runoff. The retention pond, which included up-to-date features such as a sediment forebay, was sized accordingly. The city staff estimates that this urban retrofit is removing approximately 31.8 pounds/year of phosphorus and 188.7 pounds per year of nitrogen.

Program Impact on the Chesapeake Bay

The seven completed urban BMP retrofit projects described above have provided a total of 996.8 acres of urban retrofit since 1992, 23% of the Potomac/Shenandoah basin total target and 82.9% of the increased coverage target. Total phosphorus removal from these projects is estimated at 2,544.8 pounds per year and total annual removal of nitrogen is estimated at 10,193.0 pounds. The annual phosphorus removal represents 220% of the Nutrient Strategy total basin target and 839% of the increased coverage target. The annual nitrogen reductions represent 97% of the total basin target and 368% of the increased coverage target.

In December of 1997, the City of Alexandria was awarded a Community Innovation Award by the Chesapeake Bay Local Government Advisory Committee for "its contribution and commitment to the protection and restoration of streams, rivers, and the Chesapeake Bay through the implementation of its Stormwater Urban BMP Retrofit Program -- Targets of Opportunity."

Transferability of Program

Any jurisdiction having a formal stormwater quality program, such as the Virginia Stormwater Management Program or Chesapeake Bay Preservation Program, could institute an urban retrofit program similar to Alexandria's. Detailed engineering studies need not be made to begin a program, nor are sophisticated tools such as GIS systems a necessity. A review of aerial photographs of the jurisdiction by staff engineers and storm sewer personnel is usually sufficient to identify the "targets of opportunity" for future urban retrofit upon development or redevelopment in the watersheds.

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Attachment 1
Nutrient Removal Estimates Methodology

The method to calculate loadings recommended by the Virginia Chesapeake Bay Local Assistance Department (CBLAD) and adopted by Alexandria is the Simple Method derived by Thomas R. Schueler in the Metropolitan Washington Council of Governments (COG) handbook, "*Controlling Urban Runoff.*" The Simple Method is described as follows:

$$L = P \times P_j \times R_v \times C \times A \times 2.72/12$$

where,

- L = phosphorus loadings (pounds/year--lb/yr).
- P = average annual rainfall depth (inches) = 40 inches per year for Alexandria.
- P_j = unitless correction factor for storms that produce no runoff = 0.9.
- R_v = runoff coefficient = expresses the fraction of rainfall converted to runoff.
- C = flow-weighted mean pollutant concentration (milligrams/liter--mg/l).
- A = area of development site (acres).
- 2.72 and 12 are conversion constants.

Further reducing the Alexandria constants in the formula yields:

$$L = 8.16 \times R_v \times C \times A$$

The runoff coefficient describes the fraction of rainfall converted to runoff. While dependent on soil type, topography and cover, it is most influenced by watershed imperviousness. The Simple Method uses the following formula to compute R_v:

$$R_v = 0.05 + 0.009\ (I)$$

where

I = the % of site imperviousness in whole numbers.

For watersheds with greater than 20% impervious cover, CBLAD recommends using a flow-weighted mean concentrations of phosphorus of 1.08 mg/l.

A six-month BMP monitoring project in Alexandria in 1994 established an actual flow-weighted mean concentration of nitrogen in stormwater runoff of 8.0 mg/l.

The new Virginia Stormwater Management Regulations (also to be used by CBLAD) rating for retention ponds with 2.0 inches of runoff from impervious surfaces in the permanent pool is 65% for TP.

Based on various studies reviewed, including WASHCOG's *Controlling Urban Runoff*, city staff estimates TN removal for such ponds at 40%. Pending further analysis of monitoring studies, city staff is not currently asserting any TN removal from extended detention facilities.

Retention ponds with permanent pools of less than 2.0 inches of runoff were rated using data from the *Northern Virginia BMP Handbook* and *Controlling Urban Runoff*.

Attachment 2

Total Phosphorus Reduction Calculations

Project	Urban Retrofit Acres	% Imper-vious	Runoff Factor R_v	Alexandria Constant	C TP (mg/l)	Annual LOAD TP-lb.)	BMP Type	BMP Effic'y (%)	Annual Load Reduced (lbs)
Winkler Run Pond	126.7	82.3	0.79	8.16	1.08	882.1	Ret. Pond	45	397.0
Lake Cook Retrofit	385.0	41.0	0.42	8.16	1.08	1425.0	Ret. Pond	65	926.3
Cameron Lakes Retrofit	149.3	86.6	0.83	8.16	1.08	1092.1	Ret. Pond	65	709.8
Park Center Basin Retrofit	236.9	41.0	0.42	8.16	1.08	876.9	ED Pond	35	306.9
Episcopal Center Pond	51.0	43.3	0.44	8.16	1.08	197.8	Ret. Pond	50	98.9
Slater's Village ED Retrofit	38.0	65.3	0.64	8.16	1.08	197.8	ED Pond	35	75.0
Potomac Yard Shopping Center	9.9	75.5	0.73	8.16	1.08	63.7	Ret. Pond	50	31.8
Total	996.8	–	–	–	–	–	–	–	2554.8

Total Nitrogen Reduction Calculations

Project	Urban Retrofit Acres	% Imper-vious	Runoff Factor R_v	Alexandria Constant	C TN (mg/l)	Annual LOAD TP-lb.)	BMP Type	BMP Effic'y (%)	Annual Load Reduced (lbs)
Winkler Run Pond	126.7	82.3	0.79	8.16	8.0	6534.1	Ret. Pond	30	1960.2
Lake Cook Retrofit	385.0	41.0	0.42	8.16	8.0	10,558.8	Ret. Pond	40	4222.3
Cameron Lakes Retrofit	149.3	86.6	0.83	8.16	8.0	8089.4	Ret. Pond	40	3235.8
Park Center Basin Retrofit	236.9	41.0	0.42	8.16	8.0	9897.5	ED Pond	–	–
Episcopal Center Pond	51.0	43.3	0.44	8.16	8.0	1464.9	Ret. Pond	40	586.0
Slater's Village ED Retrofit	38.0	65.3	0.64	8.16	8.0	1587.6	ED Pond	–	–
Potomac Yard Shopping Center	9.9	75.5	0.73	8.16	8.0	471.8	Ret. Pond	40	188.7
Total	996.8	–	–	–	–	–	–	–	10,193.0

Port Towns Revitalization and Environmental Enhancement - Stormwater Projects Revitalize Urban Areas

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Background

In 1993, Prince Georges County, Maryland (Figure 1) embarked upon an ambitious neighborhood revitalization program that targets communities inside the National Capital Beltway. The primary purpose of this effort is to revive older communities as attractive places to live and work. By concentrating resources and developing local institutions, state and county officials hope to stem disinvestment and abandonment of these communities.

Prince Georges County has a population of 800,000 and a median household income of $60,540. It covers 488 square miles and inclues 28 incorporated areas. Its economic wealth is tied to both Washington, DC, and Baltimore. Business is largely clustered in the northern part of the County. The county's southern area is still largely rural.

The county is bisected, geographically and economically, by the National Capital Beltway. Although the majority of the population is located in the municipalities inside the Beltway, higher income levels are concentrated outside the Beltway (Tatar, et al., 1995).

The centerpiece of the County's revitalization effort is the renewal of communities known as the Port Towns, located in the heart of Prince Georges County. What started as a thriving tobacco port and trading point along the Anacostia River in Colonial days is now a predominantly blue-collar neighborhood. Built mostly in the 1940s and 1950s, the Port Towns have fallen into disrepair and have struggled to attract new residents and businesses (Pierre, 1997).

The Port Towns revitalization initiative has generated public interest and support due to this community's keen sense of identity and heritage. With millions of dollars already earmarked for various projects, the Port Towns community is now one of the most prominent revitalization areas in Maryland.

Stormwater Revitalization Projects

What is unique about the Port Towns is that innovative stormwater retrofit projects are helping to pave the way to economic renewal. Construction of bioretention[1] streetscaping, shallow marsh wetlands, stream rehabilitation, and river restoration projects are being used to revitalize the towns. As a new urban revitalization tool, these stormwater projects are intended to mitigate adverse environmental impacts in older urban areas, improve landscaping, enhance community pride, and create a wholesome community image that invites private investment.

Port Towns

The Towns of Bladensburg, Colmar Manor, and Cottage City are collectively known as the Anacostia "Port Towns" (Figure 2) industrial and commercial activity. The Port Towns residential areas include a wide range of generally pleasant housing along with industrial and commercial activity. Economic decline in the Port Towns began due to relocation of retail shops to newer outlying malls, as well as constraints imposed by older infrastructure.

Facing similar development issues, common economies, and proximity to US Route 1, the three towns agreed to coordinate their revitalization efforts. To guide the revitalization effort, the Port Towns developed a comprehensive Vision and Action Plan in 1995. Although an extensive park or "greenway" along the banks of the Anacostia River makes an important contribution to the character of this community, the Port Towns generally lack adequate trees, streetscaping, and stormwater management controls (Legg Mason et al., 1995).

A New Revitalization Tool - Stormwater Retrofit Projects

For years, the County has considered the restoration of the Anacostia River an important part of its capital program. Although the County viewed the stormwater retrofit of the Anacostia watershed as an environmental goal, the Port Towns saw it as an opportunity to serve an economic

[1] Bioretention BMPs are stormwater retention facilities designed to mimic forested systems that naturally control hydrology through infiltration and evapotranspiration (Prince George's County Low Impact Development Manual, 1997).

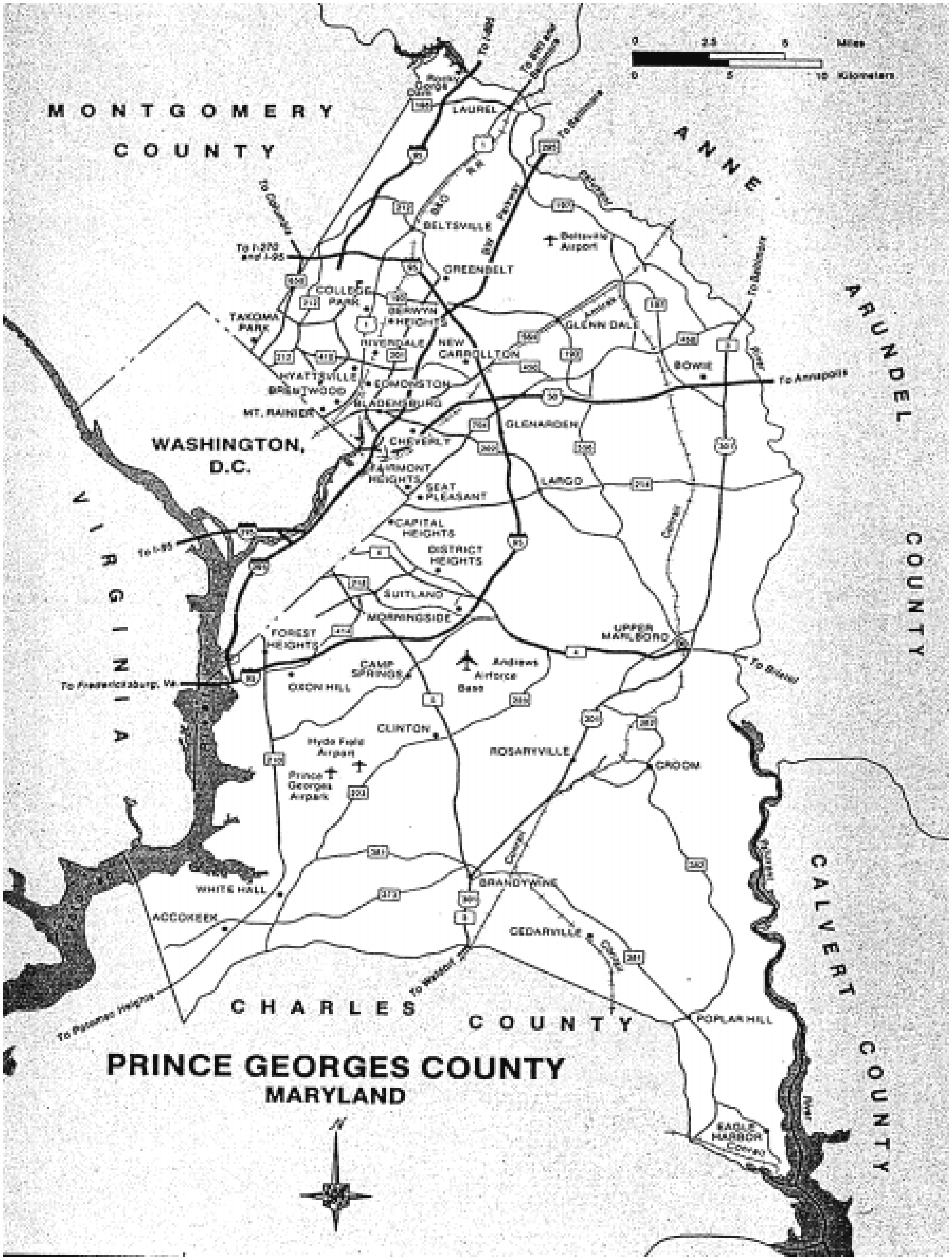

Figure 1. Prince Georges County, MD (white area on map).

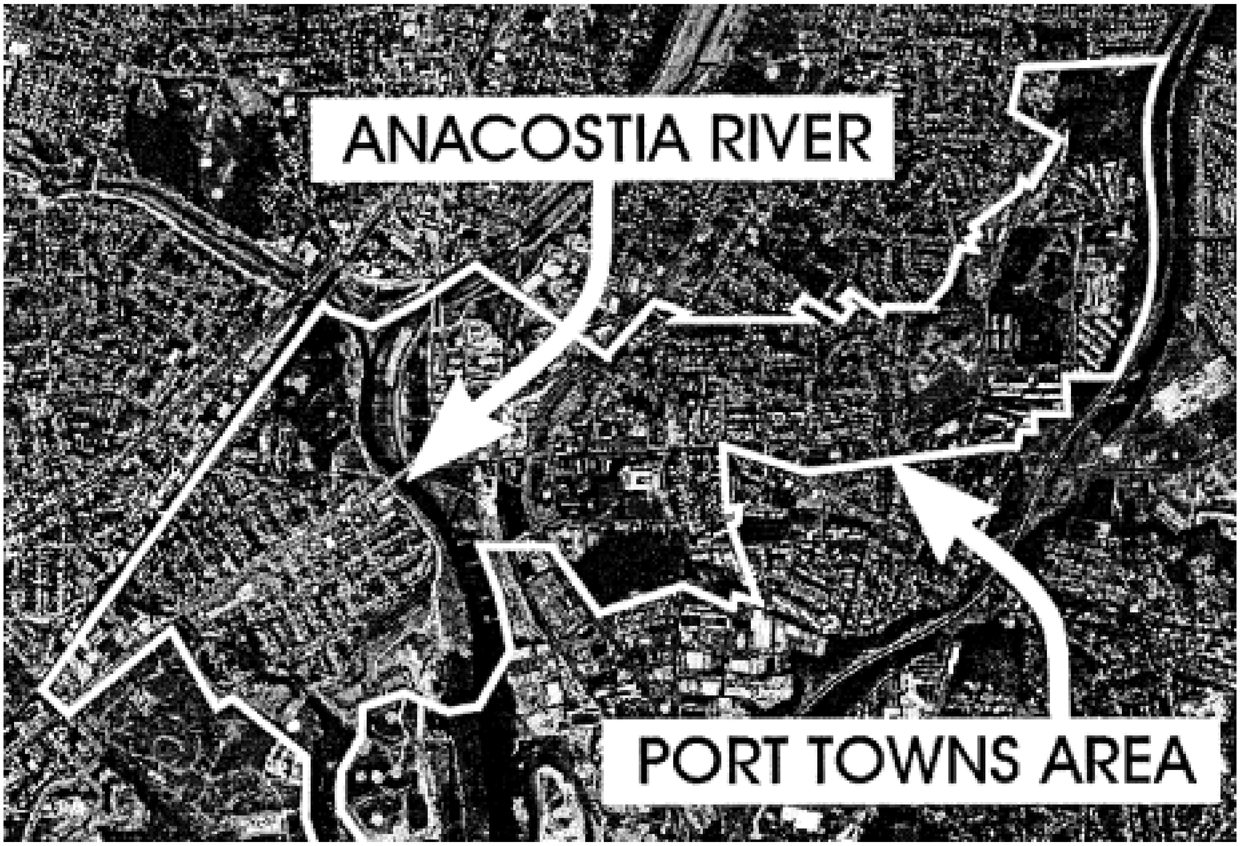

Figure 2. Aerial photograph of the Anacostia Port Towns area (outlined in white).

goal as well. Accordingly, when the Port Towns developed a revitalization vision for their community, they included the environmental restoration of the river as an important objective.

Reconstruction of river wetlands and pond retrofit, stream restoration, and bioretention streetscaping projects are now viewed not only as a way to clean the river but also as an opportunity to renew the Port Towns image. With this in mind, county and state agencies began to redirect stormwater projects to the Port Towns (and other revitalization communities). The County and the Port Towns hope to use an environmental restoration theme as a catalyst for future growth and investment. Stormwater projects are at the forefront of this new urban revitalization paradigm. Stormwater revitalization project goals are:

- Mitigate adverse environmental impacts
- Beautification
- Improve community image
- Enhance community pride
- Attract private investment

The realization that communities can help revive their economies by cleaning up their environment is not new. However, the Port Towns are probably among the first communities to envision that stormwater retrofit projects play a leading role in urban revitalization. The County's Stormwater Management Tax District and state and federal funding sources are paying for construction of innovative bioretention streetscaping, shallow marsh wetlands, and river restoration projects.

Stormwater retrofit projects can be a new tool in the repertoire of revitalization projects that help to renew older urban areas (Table 1). The basic premise is that the Port Towns stormwater retrofit and other public projects[2] will help create a more attractive place to live and work. Eventually, it is hoped that the private sector will fulfill long-term investment needs in the Port Towns.

Proposed Projects

Key Port Towns projects funded fully or partially by stormwater funds are as follows:

Port Towns Waterfront Restoration - This project involves both the rehabilitation of a river marina as a center to preserve the County's rich Colonial history and reconstruction of about 80 acres of wetlands as a waterfront park

[2] Other proposed projects include new town centers, a new railroad bridge, Brownfield projects, an ecoindustrial park, and road improvements.

Table 1. Revitalization Projects

Infrastructure	
New town center	$3M
New CSX railroad bridge	$21M
Marina redevelopment	$6M
Road improvements	$6M
Environmental	
"Brownfields" cleanup	$1.5M
Eco-industrial park	$1M
Stormwater projects	
Bioretention streetscaping, pond retrofits, stream restoration, river wetlands and drainage rehabilitation	$6M

along the Anacostie River (Figure 3). The plan proposes to increase natural wildlife habitat areas, enhance water quality, and increase economic tourism opportunities. The planned Historic Waterfront Park will be the focal point of community activities, providing opportunities for residents and visitors to gather and participate in a variety of outdoor recreational cultural, and environmental activities along the Anacostia River. Estimated costs include $6 million for the marina and $5 million for wetlands construction.

Ponds and Stream - Existing dry ponds are being converted to shallow marsh systems (Figure 4). These ponds are designed not only to improve water quality; they also include walkways, benches, and carefully designed landscaping to enhance the community's environmental, aesthetic, and recreational experiences. Eroded stream corridors are being restored to create greenways. Estimated costs are $1 to $2 million.

Urban Streetscape - In the early stages, this effort has involved the construction of several pilot bioretention streetscape projects (Figure 5) in each town. In the future, all major road corridors will be gradually reconstructed with landscaping that improves appearance and treats urban stormwater runoff. Streetscape improvements are intended to convey a sense of physical connection between the three towns and mitigate the adverse effects of pollutants found in urban stormwater runoff. Bioretention areas and other water quality BMPs will be incorporated into the streetscape projects. Estimated costs are $4 million.

Econursery - A self-sustaining nursery facility will be created for the community to grow native trees and shrubs and to produce seeds to maintain bioretention and rain garden improvements. The facility will also serve as a local science education center, a community garden, and a composting yard. Estimated cost is $300,000.

Ecoindustrial Park[3] - Environmental and infrastructure enhancements are planned for the Port Towns and surrounding industrial areas. The project will include water quality enhancements, waste minimization, and streetscape improvements. Estimated costs are $1 million. (Abbasi, 1997)

Project Funding

Funds for the Port Towns stormwater projects are provided through federal and state grants, a Stormwater Management Enterprise Fund, and the sale of stormwater revenue bonds. The debt service on bonds is paid from a tax levied on all assessable property in the County's Stormwater Management District. The current tax is 13.5 cents for every $100 of assessed property value. Under this special tax district, a 5-year, $12 million Environmental Revitalization Program has been adopted to fund revitalization projects. This amounts to about 20% to 30% of the 1999 annual stormwater capital improvement budget.

Due to the comprehensive nature of the revitalization initiative and strong community involvement, the Port Towns have drawn considerable interest from federal and state agencies (Table 2). Grants are expected to fund up to 75% of the project capital costs. For example, 50% of the river wetland project funding is expected to come from the Maryland Department of the Environment and the US Army Corps of Engineers. Up to 75% of the cost of the streetscape improvements is expected to be paid by the Maryland State Highway Administration. Funding for the eco-industrial park is expected to come from a variety of federal, state,and private sources.

Municipalities have agreed to provide for the operation and maintenance (O&M) of pilot projects. In the future, O&M costs may be shared by the municipalities and a proposed Commercial District Management Authority funded by businesses and property owners.

Site Feasibility

An inventory of several stormwater projects, divided into short- and long-term objectives, has been developed. Projects siting is based on several goals, including urban design enhancements, water quality improvements, property acquisition, permitting, and cost. Short-term pilot projects are selected on the basis of achieving quick results. Quick results lead to political and public support for revitalization and also develop institutional capacity to undertake more complex and ambitious projects (Johnson, 1997). Collectively, these environmental projects are designed to improve existing infrastructure and community appearance while helping to attract private sector investment.

Project selection begins with the guidelines of the Port Towns Vision and Action Plan. Stormwater projects are sited in commercial districts, transportation corridors, and

[3] An ecoindustrial park is generally characterized by closely cooperating manufacturing and service businesses that improve their environmental and economic performance. Industries coordinate their activities to enhance the efficient use of raw materials, minimize waste and associated disposal costs, and conserve energy and water resources. This resource efficiency results in benefits to the industires, while the surrounding community gains environmental performance and job creation benefits.

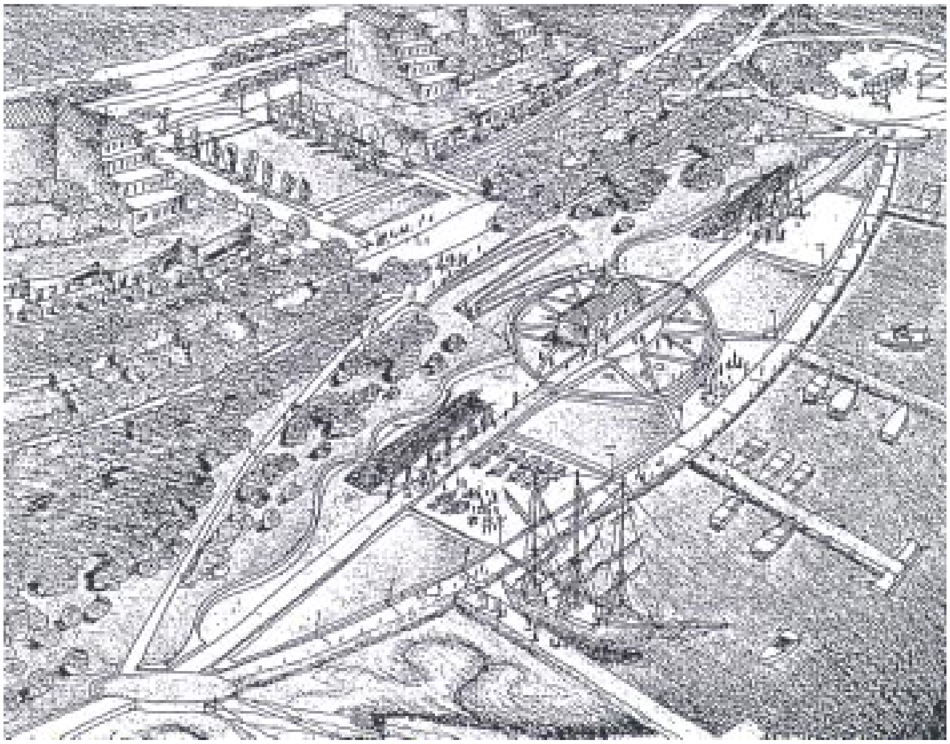

Figure 3. Drawing of the proposed historic Bladensburg Waterfront Park.

Figure 4. Dry ponds converted to shallow marsh systems improve water quality and enhance the aesthetic beauty of the Port Towns community.

Figure 5. Bioretention streetscaping (planted areas to the right of the street in the photo) help to treat stormwater runoff and improve the appearance of the community.

Table 2. Project Sponsors

- Prince Georges County Government
- Maryland National Capital Parks and Planning Commission
- Port Town Community Development Corporation
- Town governments
- Maryland Department of the Environment
- Maryland Department of Transportation
- US Army Corps of Engineers
- Commercial Management District
- Community

natural resource areas that are important renewal areas. Public exposure and acceptance of the initial pilot projects are important to enhancing visual and spatial impacts. The availability of land and easements is normally confirmed before starting the design phase. To lower project costs and to help knit a public-private partnership, publicly owned or "gratis" private easements are sought first. Permits for bioretention streetscape projects are generally easily acquired. Permits for reconstruction of wetlands in existing floodways are more complex. Extensive hydraulic modeling of the floodway channels is submitted to the federal and state governments for approval. Approval by the funding agencies is critical before the final site selection is completed.

Project Team

To guide the planning and implementation of these projects, project teams consisting of citizens and staff from various county and municipal agencies are formed. Members are also recruited from universities, nonprofit organizations, and consultants. An informal inter-agency project support group (Figure 6) leads the overall project. This organizational arrangement promotes greater integration of agency functions, stakeholder participation, and community based initiatives.

Environmental, engineering, urban planning, and project management staff are all needed for the project. Support group members provide different functions. For example, the Department of Environmental Resources provides technical support in the areas of engineering, project management, and funding coordination; the Maryand National Capital Park and Planning Commission provides community planning and liaison; and town officials, a community development corporation, and various citizen groups represent public and private interests, respectively.

Costs

To date, three small pilot bioretention streetscape projects have been completed in the Port Towns. Drainage areas for all of the bioretention projects were less than one acre in size and 100% impervious. The average cost of these bioretention retrofit projects (Table 3) amounts to $44,000 per acre of impervious drainage area.

Two shallow marsh extended-detention ponds have also been constructed in the Port Towns at an average cost of

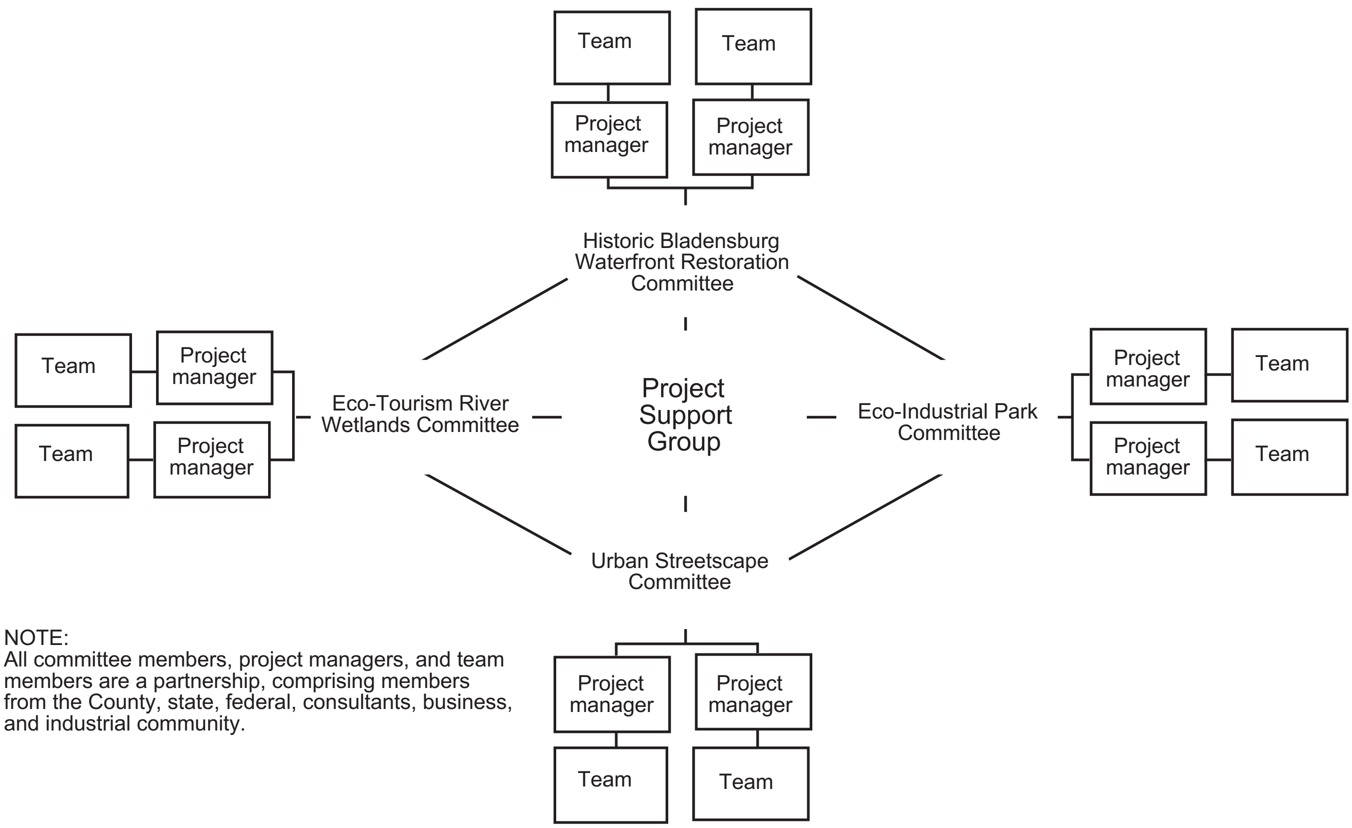

Figure 6. Port Towns revitalization organizational structure.

Table 3. Stormwater Construction Cost

Project Name	Drainage Area (acre)	% Imp.	Total Cost	Cost/acre Imp. Area
Bioretention Pilot Projects - Commercial Land use				
Chesley	.94	100%	$27K	$29K
Colmar Manor	.65	100%	$44K	$67K
Bladensburg	.66	100%	$23K	$35K
Shallow Marsh Pond - Residential Land use				
Bladensburg	230.00	55%	$395K	$3.1K
Cottage City	38.50	69%	$91K	$3.4K

$3,250 per acre of impervious area. Costs for bioretention retrofit projects in existing urban areas are relatively high due to complexities related to limited space, intense traffic controls, and presence of existing utilities. Although average costs for similar BMPs in the County over the last 6 to 8 years exceed those of projects in the Port Towns, such costs should be comparable in the longer term.

The cost of river wetlands reconstruction is expected to be much higher than the norm for the County, due to existing flood levees. An assessment of all the Port Town retrofit opportunities and their associated costs is being prepared.

Conclusion

The Port Towns is one of the first communities to envision that stormwater retrofit projects can play a leading role in urban revitalization. Stormwater retrofit projects comprise a new approach to publicly funded infrastructure rehabilitation projects that help renew old urban areas. Due to the comprehensive nature and strong community involvement of the Port Towns revitalization initiative, the projects have drawn considerable funding support from federal and state agencies.

Pilot stormwater projects were built within a 12-month period to demonstrate tangible results and achieve political and public support for revitalization projects. These projects demonstrate that stormwater projects constitute an effective tool to retrofit and improve the appearance and image of existing urban communities. Planning and design of more ambitious and complex projects are already underway, including reconstructing wetlands in the Anacostia floodway, streetscaping major transportation corridors, and cleaning up the industrial park.

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Tollgate Drain - An Innovative Approach to Stormwater Management

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The Tollgate Drainage District is a dedicated drainage district that was established, in the late 1800s to be utilized by Lansing Township, the City of Lansing, and Ingham County. The Tollgate Drain has used the City of Lansing's combined sewer system as its outlet since the early days of the City's sewer system. As part of a recent 30-year plan developed by the City of Lansing to control combined sewer overflows to the Red Cedar and Grand Rivers, the Tollgate Drainage District, under the direction of the Ingham County Drain Commissioner's Office, was mandated to implement a combined sewer separation project. Now the City of Lansing sends sanitary water to their wastewater treatment plant, while the stormwater is diverted to a wetland park detention basin and a series of detention ponds incorporated into the reconstruction of the local Groesbeck Municipal Golf Course.

Objectives

The Ingham County Drain Commission recognized the importance of redeveloping property for the dual purposes of the neighboring Fairview Park and for stormwater management. The primary goals of the Tollgate Drain project were to eliminate combined sewer overflows through sewer separation and develop a wetland ecosystem that improved storm water quality, while also meeting the aesthetic needs of Fairview Park and the Groesbeck Municipal Golf Course.

The Project

In accomplishing these objectives, the Tollgate Drain project created a wetland to act as a natural filtration system for stormwater runoff. The wetland helps maintain water quality by removing nutrients and sediments In the water. It involves the development of a stormwater separation, retention, and recharge system. The end result is a state-of-the-art urban wetland management system that uses innovative and cost-effective methods of water management.

The 210-acre Groesbeck neighborhood had a one-pipe sewer system which was built in the 1950s. This system was recently incorporated into a new two-pipe combined sewer system. One pipeline transports household waste to the C4 of Lansing's wastewater treatment plant while the other pipe, containing stormwater, is diverted. A traditional method of stormwater disposal is to drain it into the nearest river. Using an innovative method, Tollgate Drain diverts stormwater to the lowland area of Fairview Park, where it is naturally cleansed of non-point source pollutants and then recharged into the air and the ground. The water is also used to irrigate the Groesbeck Municipal Golf Course.

Most stormwater systems incorporate little if any nonpoint source pollution abatement. Stormwater picks up road oil, organic debris, fertilizers, salt and other forms of pollution as it makes its way through the stormwater system to the rivers and their tributaries. For this reason, the Tollgate Drain project is unique. Unlike other stormwater systems, it does not outlet to a river and it has nonpoint source pollution abatement properties.

Seven-Steps of the Tollgate Drain

Overall, the project consisted of seven key elements:

Step 1: Develop a catch basin maintenance plan.

Step 2: Create a filter chamber to act as a secondary cleaning chamber.

Step 3: The wetland design.

Once the stormwater reaches the wetland, it runs through mechanical oil skimmers and sediment traps which remove petroleum products and excess sand and mud. Peat-sand and limestone are used as filters in the system. Their high phosphorous (P), biological oxygen demand (SOD), pH (acidity), and pathogen removal capabilities, coupled with simple design, low maintenance, and affordability make them an attractive method. The wetland provides a variety of functions such as flood control/water storage and filtration of pollutants, and it creates eleven acres of wildlife habitat. From the Fairview Park wetland the water travels through a pipe under Wood Street to Groesbeck Municipal Golf Course where it flows into additional wetland detention ponds. This evaporates some of the water and allows the suspended sediments to further settle out. At this point, the golf course has the option to use this water for irrigation.

Step 4: The holding ponds on the golf course.

Step 5: The ultimate discharge to the City sewer at a restricted rate.

Step 6: A proactive public outreach program within the drainage district to inform and educate the district on their role in this project

Step 7: A public outreach program with a broader perspective for the community at large.

Educational Aspects

The Drain Commissioner's Office ran an extensive public outreach and education program for this project. All residents received a survey and a door-to-door visit to discuss sump pump connections and elimination of illegal storm water cross-connections to the sanitary sewer system.

An on-site office staffed with Ingham County Drain Commissioner representatives was available throughout the construction phase of the project with a hot line so that residents' concerns and questions were dealt with immediately. A door-to-door follow-up survey was conducted to obtain feedback and continue the urban storm water education.

The overall maintenance of the project depends on how the residents of the district take care of it. Residents are encouraged to participate in the success of the project by tailoring their daily activities to decrease the amount of pollution, and therefore decrease the maintenance costs. Dumping oil, pet waste, cigarette butts, or other garbage, and blowing grass clippings and other yard waste into the streets increases the number of times the catch basins will have to be cleaned out. The use of fertilizers, pesticides, and herbicides on lawns brings pollutants that can also increase the number of times filters in the system will have to be cleaned out and replaced.

Project Challenges

One of the main obstacles to overcome in the project was the "ownership" of Fairview Park. Technically, the park was owned by the State of Michigan, located in Lansing Township, and maintained by the City of Lansing as a Lansing Park. A lengthy battle over the use of the land caused uncertainty among the residents and between the different governmental agencies. Before the drainage district could proceed with design plans for the project these parties had to come to an agreement. This was the most difficult phase of the entire project and today, all parties are in agreement and cooperating fully with the Drain Commissioner's office to make the project a success.

A design challenge was to determine a cost-effective outlet for the storm sewer discharges so the sewer separation could be completed. The district is surrounded by a developed City on three sides and Groesbeck Municipal Golf Course on the west. A conventional piped storm sewer outlet to the Grand River would have had to extend over one mile through a densely-developed residential area. This option cost was in excess of $15 million. Three other routes were examined ranging in costs from $15 million to $20 million. This project, chosen instead of those options, cost $6.2 million.

Innovations/Benefits

- The key to the savings is putting nature to work. The storm water is pumped to what was once a little-used 11-acre nearby park.
- An oil and grit chamber was used to trap any oil washed into the storm collection system.
- Contaminants settle out of the water into ponds. As the water moves through connecting channels, limestone rocks buffer the acid it contains. Fast-flowing streams increase oxygen and encourage the growth of pollution-eating microbes. A peat bog filters out fertilizers and pesticides.
- The water enters a wetland where it evaporates or is recycled for more treatment. Additional water goes into water hazards at the Groesbeck Municipal Golf Course and is used for the golf course irrigation system.
- Numerous trees, plants, and grasses were planted in the system to trap contaminants. The species were selected to maximize evapotranspiration.
- The final selected system design was $6.2 million, about one-half the cost of the other options. Tollgate Drain not only saved millions of dollars, but it is a prototype for environmentally sound water management practices.
- The system not only keeps basements from flooding, but cleans the water so it can be used for irrigation at the nearby Groesbeck Municipal Golf Course.
- Storm water is managed on-site, rather than being exported.

Conclusions

In the future, direct river discharges will more than likely have to be rebuilt to accommodate non-point source pollution abatement, similar to this project, before discharging into the river. In this sense, the Tollgate Drain is ahead of its time. The Tollgate Drain involves the creation of a new wetland ecosystem designed to naturally clean and recharge the neighborhood's storm water.

Aside from the physical challenges, the success of this project is dependent upon the cooperation of the City of Lansing, Lansing Township, and the State of Michigan. But, most importantly, the future success of this project lies in the hands of the residents within the Tollgate Drainage District.

A Stormwater Banking Alternative for Highway Projects

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Purpose

The purpose of this paper is to make others aware of the approach the Delaware Department of Transportation (DelDOT) is taking toward stormwater quality management. This is a discussion paper that looks at the costs and savings of the stormwater banking approach adopted by DelDOT and provides useful information regarding program implementation for anyone considering initiating a similar approach.

Introduction

In 1996, in response to impacts from water quality control laws at both the state and federal levels, a memorandum of agreement (MOA) was drawn between DelDOT and the state's stormwater regulatory agency, the Delaware Department of Natural Resources and Environmental Control (DNREC)[1]. This MOA establishes criteria whereby DelDOT can consider a regional alternative to the on-site approaches set forth by statute. It allows DelDOT to mitigate the water quality impacts associated with highway projects elsewhere in a watershed if on-site options are not practicable. The agreement is for water quality control only. Increases in peak flow rates associated with highway development must still be controlled on-site. While the approach deviates from the on-site approach stipulated in state regulations, both parties to the agreement believe it is consistent with state and federal water quality goals.

The MOA is often referred to as the stormwater "banking" agreement. The "banking" term is used because implementation of water quality control best management practices (BMP) is tracked using a system of credits and debits. Credits and debits are accrued by watershed. Watershed delineations can be nebulous, but in Delaware DNREC officially delineated and defined 41 watersheds[2]. The MOA is consistent with this delineation. Each watershed represents a separate bank account. Water quality credits and debits from multiple highway projects may be applied to each watershed. That is, some projects may be built without providing water quality control by accruing a debit to the watershed while other projects that do build BMPs accrue credits.

This balancing of water quality credits and debits allow a more flexible implementation of water quality BMPs for each watershed. Rather than siting BMPs within the limits of specific projects, DelDOT may look anywhere in a regional watershed. It is believed this approach will direct the limited funding available for BMP implementation toward locations most conducive to water quality treatment. In this way, Delaware can realize a more cost-effective and environmentally beneficial infrastructure of water quality treatment measures.

Presently, DelDOT is the only agency within Delaware to use such a system of stormwater banking. So balancing or trading of water quality credits is only between DelDOT projects. It is hoped that other agencies will develop similar agreements so that trading of water quality credits may be conducted between multiple users. This could include both private and public entities.

Local Factors That Enable MOA Development

For those contemplating development of a similar agreement, it is useful to understand the regulatory climate in Delaware that allowed development of the MOA.

Program Delegation

EPA delegated the National Pollutant Discharge Elimination System (NPDES) permit program to the state DNREC. It also delegated the Coastal Zone Management Program (CZM) to the state. Being a delegated agency of EPA for both the NPDES and CZM programs gives the State of Delaware some latitude in implementing its surface water quality control programs.

Also, DelDOT's situation is unique among state DOT's in that DelDOT is delegated by DNREC to administer its own stormwater management program. Embodied in the state stormwater management law is a provision that allows delegation of program functions to other state agencies that can demonstrate the technical and financial abilities to implement this program. DelDOT sought and received program delegation in 1991. This gave DelDOT the ability to design, review, and permit its own projects for stormwater management.

Having control of its own stormwater permitting program affords DelDOT some freedom in program implementation. In fact, DNREC encourages each delegated agency to implement policies and procedures that address local needs and initiatives. This MOA stems from that philosophy and was developed to offer an alternate means of achieving the state water quality control goals in a way that considers the limitations of highway projects.

Need For MOA

To understand the need for this MOA one needs to understand the traditional site-specific approach toward stormwater management stipulated in the state regulations and its impact on DelDOT.

Under the state law, DelDOT is required to implement stormwater management controls on every project involving land disturbances of 5,000 square feet or more. Stormwater ponds and other control measures are required for drainage areas measuring only fractions of an acre. Highway projects, being long and linear, cut across multiple watersheds, sub-watersheds, catchments, and sub-catchments - requiring multiple stormwater ponds on every project. DelDOT has found this site-specific requirement leads to a proliferation of small expensive stormwater management ponds.

One project in particular illustrates this fact. State Route 1, North of Smyrna, Delaware, consists of a 6 mile stretch of 4-lane dual divided highway on a new alignment[3]. The preliminary project plan submittal proposed 43 ponds to manage the runoff from every drainage area affected by the project. Each drainage area was on the order of 1-2 acres. Later this number was reduced to 13 ponds by combining the runoff from multiple drainage areas. But this is still a large number, especially since it only addresses the needs for one project. When the whole transportation system was considered, it became evident to DelDOT that the site-specific approach to stormwater quality control would lead to an unsupportable expansion of public infrastructure.

Somewhat worse situations arose on widening projects where multiple stormwater ponds had to be fit into previously developed landscapes. On projects such as the widening of Naamans Road, DelDOT actually purchased homes to make room for stormwater ponds[4]. The cost included the fair market value of the homes, relocation of the residents, demolition of the existing structures, and construction of the ponds. In one case, the cost of a pond to treat less than a 2-acre drainage area exceeded $300,000.

Because of the SR-1 and Naamans Road experiences, in the fall of 1994 DelDOT took an inventory of all stormwater management facilities planned for construction over the next 6 years (FY95-2000). An examination of project plans indicated that at least 114 new stormwater management ponds were in some stage of design or construction. Of those facilities, a representative sample of 37 ponds examined to determine some average conditions that could be applied for cost estimating purposes:

- The average land area required per pond — 0.75 acres
- The average volume required per pond — 3,000 cubic yards
- The average depth of the ponds — 4 feet
- The average cost of real estate — $25,000/acre

From these parameters, stormwater pond construction was estimated by applying the mean cost of DelDOT construction pay items. The cost per pond came to $85,225. This included real estate acquisition, design, and construction costs. The projected construction cost for all 114 ponds was estimated at $9,715,650.

The inventory and cost estimate also included other types of stormwater management practices planned for implementation on DelDOT projects for this time period. Included were infiltration trenches, biofiltration swales, and sand filters. Their costs were estimated to be $497,460. The total construction cost of all stormwater management practices for the 6-year period (FY1995-FY2000) was estimated at $10,213,109.

Compared to the $463,349,000 Capital Transportation Improvement Program Budget for this period, the cost of stormwater quality control implementation amounted to only 2.2% of the budget. But while 2.2% may seem small, it still amounts to a substantial investment in public infrastructure. And certain recent projects raised doubts as to whether the limited funds available were being used in the most effective manner.

For example, the Lancaster Pike widening project included 816 linear feet of sand filters to treat the runoff from about two acres of roadway pavement[5]. Of the two acres, only about one acre was new pavement. The cost for the filters was $326,400. It seemed exorbitant to managers at DelDOT, but at the time of design no alternative existed. The project's steeply sloped and high-cost real estate surroundings were not conducive to less-expensive options and the on-site requirements in the regulations obligated DelDOT to provide water quality control for this drainage area. This project caused DelDOT managers and members of the public to question whether the high cost of water quality control was worth the seemingly miniscule environmental benefit which was difficult to measure. Because of this and several similar situations on other projects, DelDOT and DNREC collaborated to devise a better way.

The Stormwater Banking Concept

The quality of water in a stream depends on many factors - just one of which is stormwater runoff. When considering non-point sources of pollution, it is commonly thought that all land surfaces contribute some degree of pollution. And the relative amounts of pollution will vary naturally within watersheds from one sub-area to another. In this context, the quality of stormwater runoff from any single sub-area is not a significant determinant of stream water quality. Pollution levels then can be increased or decreased from one area to another with no adverse affect to stream water quality. As long as the cumulative impact to the stream stays the same, or is reduced, stream water quality will be preserved or even enhanced. The MOA is based on this concept of balancing the levels of pollution from multiple sub-watersheds.

Specifically, the MOA allows DelDOT to provide stormwater quality.controls at an a tentative location in the event the implementation of similar controls at a specific project site is not practicable. The measures installed at alternate locations must provide stormwater quality treatment for an equivalent amount of highway runoff as that going untreated at the project site. In choosing alternate locations, preference is given to sites within the same watershed as the project. Projects requiring water quantity control must still address it on-site. Ways of providing water quantity control without building a pond are discussed in appendix 'A' of the MOA.

This concept of balancing stormwater treatment from one area to another, literally treating some areas while letting other areas go untreated, is often referred to as stormwater "banking". And, as is the case with Delaware's MOA, the concept normally uses an accounting system of credits and debits to track the overall level of water quality control implementation in each watershed - hence the term "banking".

Stormwater "banking" offers an alternative to the site-specific approach by helping to facilitate a regional planned approach to stormwater quality management. Regional planning for water quality control involves prioritizing the various water quality treatment needs in each watershed and targeting implementation of control measures in the locations they will do the most good. In theory, this should minimize the overall number of stormwater management measures and maximize their cumulative effectiveness. In this way, taxpayers should receive the greatest return on their investment in public infrastructure designed to treat highway runoff - both in terms of initial construction costs and long term maintenance.

This stormwater "banking" concept is not particularly new or original. Similar approaches are frequently employed on projects all over the country. But it is seldom well documented and is often viewed as bending the rules. This MOA formalizes the criteria by which DelDOT will determine compliance when it is not practicable to manage stormwater quality "on-site". And it validates the approach as an acceptable alternative.

MOA Triggered by Variance

It should be noted that DNREC was reluctant to depart completely from the requirement to manage stormwater quality on-site. In Section 2.2 of the MOA, it was DNREC's desire to limit the use of stormwater "banking" by allowing its use only after first exhausting all on-site alternatives. In its final form, the MOA is reserved for projects located in areas that pose difficult site constraints or which otherwise offer little opportunity to implement permanent water quality control measures on-site. The terms of the MOA may be invoked only through the granting of variance in accordance with Section 3.3 of the Delaware Sediment and Stormwater Regulations. Variances may be granted only after demonstrating that exceptional circumstances exist at a project site which would result in unnecessary hardship and not fulfill the intent of the regulations.

Site Selection

Selection of appropriate sites for stormwater banking is accomplished through guidance provided by DNREC watershed managers. The MOA encourages a collaborative effort in selecting a site.

Section 1.2 of the MOA defines 41 regional watersheds which is consistent with the delineation established by state and federal water resource managers (see the-draft Delaware Wetland Banking Agreement)[2]. It is preferable under the MOA to mitigate the water quality impacts from a project within the same watershed. However, if the committee of resource managers established under Section 3.4 determines it is appropriate to mitigate outside the watershed, then this option may also be considered.

Types of Water Quality Control Alternatives Allowed

Section 3.3 of the MOA lists the alternative types of water quality treatment methods available to DelDOT. The goal of this section is to encourage the use of alternative water quality control methods that best meet the water quality control needs for each watershed. The available options focus on protecting key natural areas such as streams and wetlands. Other banking agreements reviewed emphasized providing only stormwater management ponds or infiltration measures[6]. DelDOT and DNREC felt it was important to encourage wetland creation, restoration, and enhancement as a water quality improvement measure. The list includes: source controls, removal of existing pavement, reforestation of cut woodlands, replacement of riparian vegetation, retrofitting existing stormwater ponds, removal of illicit connections. The list itself is not meant to be all-inclusive. All reasonable water quality improvement techniques will be considered under this MOA provided they help meet the water quality goals for the watershed being considered.

One alternative that was considered, but later ruled out was conservation/preservation easements. This option would have allowed DelDOT to purchase the development rights to lands deemed worthy of protection such as upland forests which are extremely important from a water quality perspective. Unfortunately, DNREC felt this option did not mitigate increased pollution. As they saw it, preservation easements only maintain the status quo. DNREC argued that if DeIDOT were allowed to increase pollution at one location in a watershed, then an equivalent amount needed to be reduced elsewhere. Preservation easements did not meet that test.

Accounting System

Section 3.5 establishes the accounting procedures for water quality debits and credits. They are accrued by watershed and each watershed can be thought of as a separate account. Currently, DeIDOT is tracking the number of credits and debits using Microsoft Excel software.

Counting credits and debits seems like it ought to be a fairly easy thing, but it becomes very complicated if certain factors are considered such as whether the land treated is impervious, farmland, subdivision, or forest. Questions arise such as, is it fair to give equal credit to a measure that treats runoff from fallow fields as one treating roadway runoff. Other complicating factors include whether the treatment measure is in the same watershed as the project. Should it be given equal credit? Maryland's agreement attempts to consider these factors. DeIDOT decided this approach was just too cumbersome for our purposes. We limited the credits to the actual acreage of impervious surface treated. Even with this simplification, a supplemental worksheet was prepared at the request of project designers struggling with the accounting of water quality credits and debits.

Modification and Termination of MOA

It was important that both parties have the ability to alter the agreement. Since the regional concept had not been tried in Delaware previously, neither party was quite sure how well the concept could be implemented with this simple agreement. It is expected that the MOA will need updating from time to time as our understanding of the regional stormwater management approach matures. Therefore, Sections 3.4 and 3.7 of the MOA allow for modifications upon written agreement of both parties.

Both parties acknowledge the agreement relies heavily on a mutual understanding of each agency's needs and limitations. It will succeed as long as conditions exist which foster a cooperative spirit. This could change over time because of political or personnel changes which might result in philosophical differences. Should the relationship degrade, the MOA may be terminated upon written notification by either party in accordance with Section 3.8.

Funding of Stormwater Banking Projects

The MOA itself does not stipulate the way DeIDOT will fund stormwater banking projects. Funding opportunities will vary over time so there seems no reason to create binding arrangements in the agreement. The agreement does, however, establish a funding time frame under Section 3.5. This Section obligates DeIDOT to fund a banking project to mitigate for previous debits within three years of first using the MOA.

There is no expectation that federal or state grants will help fund this program. Rather, funding will be part of DeIDOT's operating and capital improvement budgets. However, DeIDOT is investigating other funding options. Current funding options being used or considered include the following alternatives:

1. Banking projects funded as component of highway contract

2. Percentage of contract cost held in escrow from multiple projects or programs

3. Public-private partnerships

4. Public-public partnerships

Under item (1), if banking can be accomplished within the limits of an existing project, the costs can be made part of that project. Normally, this is done when an opportunity exists to manage the runoff from more land than what is required under the project, such as adjacent existing highway. In this way, water quality credits are accrued for the watershed in question. Future projects then may be built without stormwater quality controls by taking debits against the credits accrued by earlier jobs.

Under item (2), DeIDOT will hold a certain percentage of program funds aside for stormwater banking implementation. For instance, this is being done with DeIDOT's Pavement Management Program which funds pavement overlays, shoulder paving, and minor (1'-3') lane widening projects. In FY99, 1% of program funding ($320,000.) is being set aside to address water quality concerns arising from this program. The amount set aside is based on an estimate of additional acreage of impervious surfaces created under the program. Mitigation efforts will be focused in one or two high-priority watersheds to balance the impacts of many projects from multiple watersheds around the state. Under this scenario, highway projects may be started prior to actually having a banking project initiated. So long as the funding is available, the impacts from earlier projects can be mitigated within the 3-year time limit.

Item (3) has been discussed but no agreements have been reached as of this writing. However, it is envisioned that a private developer or group of developers could partner with DeIDOT to build one or more regional facilities that manage the runoff from both private and public land. There are multiple ways to fashion a partnership under this scenario. The main bargaining chips include land, design services, construction, and future maintenance.

The public-public partnership under item (4) presents itself in locations where multiple public agencies share real estate, but maintain separate operating budgets. DeIDOT has identified several locations where other state agencies, local governments, and school districts may partner with DeIDOT to share the costs of building and maintaining a stormwater banking facility. No agreement has been signed to date, but several are in draft stages.

Both options (3) and (4) rely on equitable distribution of costs. DeIDOT is settling on a formula of distributing costs based on percentage of land contributing runoff. The cost to each partner is the total cost multiplied by each partners respective acreage of land as a percentage of total acreage contributing runoff to the facility. This formula is used to divide construction costs. It can also be used to determine each partner's annual share of maintenance costs.

Property Acquisition Concerns

It remains to be seen what authority DelDOT will be able to exercise in acquiring property for stormwater projects when it has to mitigate for highway jobs located a considerable distance away. There was concern that DelDOT would never be able to settle on a site because property owners would argue that we could always locate it somewhere else. In his legal review, the Deputy Attorney General (DAG) felt that DelDOT would enjoy all the same authority we have now. That is, if we needed property for stormwater management purposes we could obtain it either voluntarily or through invoking the state's right of imminent domain. The DAG's opinion was that as long as we can show that the sites we pick are the most practical and feasible locations we would be justified in the taking. He did not think we would need to prove the chosen sites are the only feasible locations[7].

Cost Comparison on Porter Road Project

Phase I of the Porter Road widening project serves as a good example to illustrate the potential savings of the regional approach allowed under the MOA. The project begins at the intersection of Route 896 and extends 2.225 miles East to the intersection of route 72. It involves the widening of the existing 18-ft roadway to a variable width of 48 - 60 ft. The project has outfalls to three of the 41 watersheds defined in the MOA. Within those watersheds, 13 sub-areas were identified as requiring separate stormwater management measures. The initial design was submitted with 13 stormwater management ponds to control the increased peak rates of runoff and non-point source pollution associated with the roadway project for each of those 13 subareas. The proposed measures would treat the runoff from only those areas within the immediate project limits. Their design was typical of small-scale stormwater ponds, lacking in aesthetic appeal and marginal in the overall water quality benefit to downstream areas. The estimated cost of this site-specific approach was in excess of $1 million.

Later it was determined that the MOA criteria would offer a better alternative for this project. The design proposed building wetlands instead of stormwater management ponds. The revised design included the following components:

- Wetland creation in the headwaters to Belltown Run to prevent downstream flooding and improve water quality,

- Restoration of 1 acre of previously filled wetland at the Porter Road Belltown Run crossing restoring flood plain storage and stream habitat,

- Retrofitting of an existing county owned stormwater pond to incorporate water quality control components (i.e. with extended detention), and

- Enhancement of an existing degraded wetland at the Porter Road and Route 72 intersection which involves the eradication of phragmites and creates wetlands in the upland areas adjacent to a narrow band of existing wetlands.

In addition to treating the runoff from the Porter Road project, an additional 25 acres of existing roadway was afforded water quality treatment that accrued as credits in the Christina River watershed. These credits are being used to balance the water quality impacts from the Salem Church Road project in the same watershed. The cost of this approach is estimated at $1.2 million. However, substantial savings will be realized when future projects make use of the credits afforded by the Porter Road Project.

This comparison illustrates the potential economic savings that can be generated through use of the MOA but DelDOT believes the measures installed under the MOA are also more effective from an environmental standpoint. The larger scale of these facilities allows more innovation in design resulting in many secondary benefits in terms of wildlife habitat, aesthetics, and public acceptance.

Consistency with Federal Surface Water Quality Control Programs

It was DelDOT and DNREC's intent to ensure the MOA was consistent with other water quality control programs at the state and federal levels. Section 2.1 of the MOA makes very general statements regarding this consistency merely to confirm that in fact these programs were considered. A more in-depth discussion of how the MOA meets the water quality requirements is provided below.

TMDL Program

Section 303(d) of the Clean Water Act requires states to develop a list of water bodies that need additional pollution reduction beyond that provided by the application of existing conventional controls. The law requires states to identify all waters needing water quality improvement. Those portions of streams not meeting designated use standards are termed “Water Quality Limited”.

Water quality limited waters require the application of Total Maximum Daily Loads (TMDLs) to determine the allowable stress for each stream. A TMDL is the level of pollution or pollutant load below which a water body will meet water quality standards and thereby allow designated use goals, such as drinking, water supply, swimming, fishing, or shellfish harvesting to be achieved.

The TMDL approach to watershed management recognizes that streams have a certain capacity to carry pollution without any discernible impact to the designated use of a stream. It recognizes that restoration of stream water quality may require a balancing of pollutant loading from multiple sources in a watershed. The MOA is consistent with this concept and may to some extent help facilitate a system of trading water quality credits between multiple users within a watershed.

NPDES Stormwater Permit Program

Section 402(p) of the Clean Water Act establishes permit requirements for certain municipal and industrial stormwater discharges. New Castle County, Delaware was identified under the Phase I NPDES Stormwater Permit program as requiring a permit for the discharge of stormwater from the municipal separate storm sewer system (MS^4). Also, all construction activity disturbing more than 5 acres of land was identified as an industrial activity requiring a stormwater discharge permit. This legislation affected all storm drains owned and operated by DeIDOT in New Castle County and also affected DeIDOT construction activity statewide.

The statute mandated that owner/operators of storm sewer systems implement regional stormwater management plans utilizing a watershed approach. Stormwater banking ran be a component of such a plan.

The concept of banking stormwater quality improvement credits is consistent with the federal statutory requirement of implementing controls to reduce the discharge of pollutants from municipal separate storm sewer systems to the maximum extent practicable. The operative phrase in the statute is, "reduce... to the maximum extent practicable". Neither the law nor the regulations requires the discharge of pollutants associated with stormwater runoff to be eliminated or reduced at all cost. While the implementation of stormwater quality controls on each and every transportation project may be a desirable goal, it is recognized such a goal may not be realistic, cost effective, or practicable.

DeIDOT believes it will be able to demonstrate compliance with the legal intent of the statute because the banking approach is based on the water quality control needs of the overall watershed. This is especially true if DeIDOT can show consistency with the TMDL for each stream section. However, It may be possible for a citizen to lodge a complaint under the statute if there is a measurable increase in pollution at a specific site where water quality controls were determined to be impracticable to implement These types of complaints would likely come when a water quality impact is readily noticeable by the general public, such as where a storm drain discharges trash, debris, sediment and the like from a roadway onto adjacent property. This would most likely be the case on new alignments if control measures were not implemented. Improvements to existing alignments would not be as likely to generate these types of complaints because roadway type pollution would already be present. Adding another lane under a widening project is not likely to change the character of the pollutants to a great degree, although the total mass of the various pollutants may increase slightly.

For these reasons the agreement emphasizes the implementation of water quality controls onsite for major roadway improvement projects, such as new alignments. It encourages utilization of the banking concept only on more minor types of projects, such as intersection improvements and lane widening projects where it is typically more difficult to incorporate stormwater management measures. Also, a maximum debit limit of 5 acres is allowed to accumulate statewide before it must be mitigated by implementation of a water quality control project. The 5-acre limit was chosen to coincide with the 5-acre limit established in the NPDES stormwater regulations for construction activity. The law requires implementation of water quality controls when 5 or more acres of ground is being disturbed by construction. Under the agreement, DeIDOT may do several small projects each disturbing a fraction of the 5 acres. But once the aggregate of all watersheds exceeds the 5-acre limit, DeIDOT must undertake a project to mitigate for those cumulative impacts.

Coastal Non-Point Pollution Control Program

Section 6217 of the Federal Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 mandated that each state in the coastal zone initiate a coastal non-point pollution control program. The intent of the law was to encourage EPA, NOAA, and the states to place special and expeditious attention on protecting the nations coastal water from urban sources of nonpoint pollution.

EPA excluded from coverage under Section 6217 all stormwater discharges covered by Phase I of the NPIDES stormwater permit program. That is, any stormwater runoff that ultimately is regulated under an NPIDES permit will not be subject to the requirements of Section 6217 of the CZARA once the permit is issued. For instance, discharges of stormwater from construction activities disturbing more than 5 acres of land and New Castle County's municipal separate storm sewer system were excluded from the Coastal Non-point Pollution Control Programs.

That still left several sources of pollution that needed to be addressed under the Coastal Zone Act. Specific areas affecting DeIDOT included requirements to control runoff from existing roadways and bridges and runoff from construction sites that result in the disturbance of less than 5 acres of land.

The notion of building stormwater treatment measures as the only item of work was not commensurate with the mission of DeIDOT which is to build transportation systems, not water quality treatment systems.

Fortunately, the Section 6217(g) Guidance encouraged a whole watershed planning approach in implementing stormwater management measures. Again, the MOA on stormwater banking is consistent with this concept and may to some extent help facilitate the process. From DelDOT's perspective, the MOA helps DeIDOT justify the expenditure of transportation funds on water quality control measures for existing roadways and bridges. As discussed above, the implementation of stormwater management control measures in accordance with the terms of the MOA can be less expensive than a site-specific approach. There is an economic incentive then for DelDOT to undertake projects solely for the purposes of treating stormwater runoff because of the savings accrued to future roadway projects.

Section 404 Wetfands Permitting Program

The MOA allows the implementation of many alternative types of surface water quality control measures, one of which is creating wetlands. Wetland creation in areas designated as uplands will provide stormwater quality treatment in accordance with the stormwater regulations. With the US Army Corps' concurrence, it may also qualify for wetland mitigation credits required for highway projects.

In searching for a site to build a regional stormwater management facility, if is often the case that a stream or wetland is identified as the only feasible location. However, it is not usually possible to acquire permits to locate stormwater management measures in existing wetlands, nor does the MOA encourage this activity. Under certain circumstances, however, the regulatory agency may believe work in a wetland is beneficial to the resource such as by restoring a previously filled wetland. For instance, DelDOT has restored previously filled wetlands for mitigation credits on several projects. If these restored wetlands rely on surface runoff from roadways to provide the hydrology needed to support the wetland, then stormwater quality credits may also accrue under the MOA for the watershed in question.

Conclusion

The on-site approach to implementing water quality treatment measures encourages a proliferation of small, expensive, and maintenance intensive practices on DelDOT highway projects that may not offer the best solutions needed for the watersheds in question. Stormwater banking offers one possible alternative because it allows implementation of treatment measures anywhere in a watershed so they may be targeted toward the areas they are needed most.

Delaware's MOA allows a broad array of treatment methods, such as wetland creation, reforestation, and elimination of existing pavement. This is intended to encourage innovation in meeting the water quality requirements and protect key natural areas. The MOA also offers a uniform procedure for tracking water quality credits and debits accrued in each watershed. DelDOT is finding the stormwater banking approach to be more flexible and cost effective than the traditional on-site approach.

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Financing Retrofit Projects: The Role of Stormwater Utilities

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To achieve national water quality objectives, we must retrofit existing stormwater infrastructure to manage pollution in runoff. Many public works and water resources professionals have suggested that stormwater utilities are an important, if not essential, funding source for retrofit projects. We examine in this paper the role of stormwater utilities in financing retrofit projects and programs. Based on a broad assessment of the need for funding and a brief overview of the evolution of stormwater utilities, we conclude that stormwater utilities are perhaps the best institutional approach to financing retrofit programs, but that they are not a panacea. The major issues in implementation of effective retrofit programs will be economic and therefore political. Stormwater managers can help constrain and focus political debate through careful analysis.

How Much Do Retrofits Cost? What is the Need For Funding?

The answers to questions about the costs of retrofits and programs to control the quality of stormwater runoff depend on many different factors. These factors include the characteristics of runoff quantity and quality, the size of the watershed where projects are being planned, the severity of water quality problems, the water quality objectives, and the types of best management practices that are being proposed. A short, safe answer that recognizes variability among places is that programs will be expensive, ranging from tens of thousands of dollars in relatively small places to achieve modest objectives, to tens or hundreds of million dollars in larger cities with moderate to severe problems.

We provide here several brief examples of the potential magnitude of costs of retrofit programs. Our examples are by no means exhaustive and they are not necessarily representative. We have chosen published estimates or used cases with which we are familiar simply to demonstrate that experts believe costs will be significant and controversial. These examples should be sufficient to convince skeptics or individuals who have not thought systematically about the economic aspects of retrofit programs, that a critical task in implementation of a program is identification of sources of revenue.

Our examples include estimates of the costs of programs at the national level, for a watershed, for a large city, and for a small town (Table 1). In a project for the American Public Works Association, James M. Montgomery (1992) estimated the capital and operation and maintenance (O&M) costs for large and medium cities to comply with EPA's stormwater rule. Capital estimates ranged from $147 million to more than $400 billion, depending on assumptions about the level of treatment for runoff. Estimates of O&M costs ranged from $1.2 billion to more than half a trillion dollars, again depending on assumptions about level of treatment. Reasonable questions can be raised about these estimates. Some experts suggest that they are too high because advanced treatment never has been contemplated for stormwater. Other critics contend that these estimates were made primarily for political purposes and to support opponents to the then-proposed federal stormwater rule who argued that costs were prohibitive. Regardless, they are suitable for our purposes. They demonstrate clearly the need for financing and they show that the costs of programs will be controversial.

More recently, EPA modeled the Phase I Storm Water needs to inform Congress of the costs of programs to control pollutants in urban runoff. Approximately 266 Phase I stormwater permits that regulate about 850 municipalities will be issued. The Phase I needs estimates were prepared to determine the stomwater management costs that might be eligible under state revolving fund (SRF) loan programs. The SRF-eligible costs include costs for developing and implementing municipal management programs, including capital costs for structural controls and BMPs. The total modeled costs are $7.4 billion. These costs do not include O&M costs, costs of land acquisition, permitting costs, costs of developer-financed BMPs; or several other categories of costs. These estimates, which were subject to peer review prior to their release, also are significant. These esti-

Table 1. Selected Costs for Stormwater Programs

	Capital	O&M
	Estimated Costs for BMPs in Regulated Municipalities (Montgomery 1992)	
1. Source controls	$147,100,000	$1,155,000,000
2. Increased maintenance + 1	$147,000,000	$32,607,800,000
3. Construction of moderate controls + 2	$83,139,500,000	$86,223,700,000
4. Construction of detention basins + 3	$91,130,900,000	$90,097,500,000
5. Advanced treatment plants + 4	$406,734,900,000	$542,036,700,000
Estimated Costs for Phase I Storm Water Programs (EPA 1997)		
Modeled SRF-eligible costs	$7,400,000,000	
Costs for Pollutant Reduction in the Menomonee River Watershed, Milwaukee, Wisconsin (WDNR 1992)		
Core (source controls)	$3,400,000	
Segment (planned, new areas)	$11,700 000	
Segment (existing areas)	$94 - $184,000:00	
Total	$110 - $200,000,00	
Estimated Rehabilitation Costs in Indianapolis, Indiana		
Capital	$283,000,000	
Household	$54	

mates also have political dimensions; they were prepared to inform Congressional debate over funding for water quality programs.

In general, better cost estimates can be made for smaller geographic areas because site specific factors can be taken into consideration and fewer general assumptions need be made. The Wisconsin Department of Natural Resources (1992) has estimated the costs to achieve pollutant reduction objectives for the Menomonee River in Milwaukee, Wisconsin. The Menomonee River watershed is 136 square miles, is 60% urban, and contains 18 municipalities and parts of four counties. To meet ambient water quality standards, programs are needed to reduce sediment by 50%, phosphorus by 50%-70%, and lead by 35%-70%. The corresponding cost estimates for “segment” controls for existing areas of development range from $94 million to $184 million.

In many of the nation’s larger cities, stormwater infrastructure has fallen into disrepair, and significant investments will be required simply to meet generally accepted engineering standards for stormwater conveyance and flood control, let alone implementation of BMPs to meet water quality objectives. In Indianapolis, Indiana, for example, a mayor’s blue-ribbon panel estimated the costs to rehabilitate stormwater infrastructure at $283 million. The infrastructure includes 1750 miles of storm sewers, more than 1000 outfalls, more than 50 miles of levees, and a number of regional detention ponds. The panel did not estimate costs for programs to manage pollution in runoff.

In smaller towns, individual projects that in larger cities would be considered routine can pose significant burdens. In Vincennes, Indiana, a city with a population less than 20,000 and a median household income two-thirds of the state median, the city is responsible for pumping water from a drainage ditch over levees into the Wabash River whenever water in the ditch reaches specified elevations. The pumps are more than 50 years old and are in poor repair. The city estimates annual costs for City Ditch to be approximately $50,000, but no existing sources of revenue are available to pay for rehabilitation and related O&M costs.

In sum, while the estimated costs of retrofits vary tremendously with the scale and scope of a program, invariably new sources of revenues will be required to pay for new programs. The costs of programs are debated by officials who have responsibility for implementation of them. Stormwater utilities have emerged from these debates as the option of choice to fund new programs.

How Can Retrofit Programs Be Funded? What Are Stormwater Utilities?

Most jurisdictions historically have paid for investments in stormwater infrastructure with revenues from property taxes and other general revenues. Many, if not most jurisdictions, now rely on a variety of sources to finance comprehensive stormwater programs. Table 2 is an abbreviated list of sources of revenues available to pay for different elements of stormwater programs. One key observation from this list is that the sources of revenues most important for retrofit programs are property taxes and stormwater user charges.

Stormwater user charges or fees are charges based on some indicator or proxy for the actual volume of stormwater runoff that leaves a property. The most common type of charge is based on the amount, or square footage, of im-

Table 2. A Functional Approach to Stormwater Financing

BMP	Option
• Watershed planning	- general revenues (property, income taxes) - stormwater user charges
• Source controls - Enforce ordinances - Development regulation	 - general revenues, stormwater user charges - plan review & inspection fees
• Maintenance (e.g., street sweeping)	- general revenues - stormwater user charges
• Capital projects - new development - retrofit existing areas	 - developer exactions, fees-in-lieu - bonds, sinking funds - general revenues, stormwater user charges

pervious area on a parcel. Other bases for stormwater charges include the area and proportion of impervious cover on a parcel, the intensity of development, and the type of land use. In some instances, an estimate of the actual volume of runoff or some estimate of the concentration of pollutants in runoff may be used as the basis of charges. Examples of rate structures are shown in Table 3.

Stormwater charges usually are administered by a stormwater utility, an administrative unit or institution established within or across jurisdictions for the purpose of managing runoff and related problems. Revenues collected by utilities are placed in separate enterprise funds or accounts and can be used only for stormwater related expenditures. The first stormwater utilities were established in the mid-1970s, primarily to provide sources of revenue for maintenance of stormwater infrastructure. Since the 1970s, the number of utilities has grown tremendously, fueled in part by the efforts of stormwater managers desperate for funds to do their jobs.

Since the 1980s, as part of efforts to develop new sources of revenues for stormwater programs, a number of surveys of stormwater utilities have been completed. Table 4 is a summary of some of the results of these surveys. Important observations include:

- Average annual charges for residential property owners range from $15 to $130.
- Average annual charges have increased over time.
- Stormwater charges are the source of most revenues for most stormwater utilities.
- The proportion of charges from different types of property varies considerably.
- Total revenues from charges are significant and increasing.

What Are the Advantages and Disadvantages of Property Taxes and Stormwater User Charges? Why Has the Number of Stormwater Utilities Increased?

Stormwater utilities and user charges offer a number of advantages over property taxes, the main alternative, although taxes are preferable by some criteria (Table 5). It is useful to consider the drawbacks of charges first. Stormwater user charges are more difficult and costly to implement than are taxes because institutions and procedures to levy and collect taxes are already in place. User charges are not deductible from federal and state income taxes, and they are not elastic. Property taxes, on the other hand, are deductible, and revenues from them increase as property values appreciate without explicit decisions by officials to increase rates or levies. Revenues from user charges increase only if officials vote to increase rates.

Despite these disadvantages, reliance on stormwater user charges is increasing, partly because user charges are perceived as a more stable source of revenues. As noted above, revenues from charges are placed in enterprise funds and can be used only for stormwater related expenditures. Funding from general revenue sources like property taxes is never secure because of fierce competition among political leaders and program managers for scarce dollars. Under property tax systems, stormwater managers often cannot count on budget allocations, do not have as much control over their budgets, and cannot plan as well.

Perhaps the most important reason that the number of user charge systems is increasing is that property owners believe charges are fairer. Impervious area - the basis for most stormwater charges - can be measured and is a reasonably objective measure. The idea that property owners pay in proportion to the measured amount of hard surface on their property seems fair. Property values, conversely, are unrelated to the problem of runoff and perceived as highly subjective. Many surveys suggest that property taxes are the least popular form of tax.

A final reason that charges are preferable to taxes is that they provide incentives for property owners to reduce the amount of impervious area on their property and thereby reduce volumes of runoff. Depending on how credits against charges are structured, they also can provide incentives for on-site management

Local officials routinely consider these tradeoffs when evaluating sources of funds for new programs like retrofit programs. Because perception of fairness is such an important factor in public finance, it is useful to elaborate on the issue of equity.

Who Pays More Under Property Tax and User Charge Systems?

Although charges typically are perceived as fairer than property taxes, this does not necessarily mean that any

Table 3. Utility Rate Structures in Austin, Cincinnati, and Ft. Collins

Austin, Texas		Cincinnati, Ohio		Ft. Collins, Colorado		
Land Use Categories	Rate Factors	Rate Categories	Intensity of Development Factors	Basic Category Development	Runoff Coefficient	Rate Factor
• Undeveloped	.10	•Class A Residential (< 10,000 sq. ft.)	.25	•Very Light	.00-.30	.25
• Residential	.40	•Class B Residential (> 10,000 sq. ft.)	.20	•Light	.31-.50	.40
• Nonresidential	.80	•Class C		•Moderate	.51 -.70	.611
		- Commercial	.85	•Heavy	.71-.90	.80
		- Industrial	.75	•Very Heavy	.91-1.0	.95
		- Multi-family	.60			
		- Transportation	.50	Runoff Coefficient (C)		
		- Institutional	.40	C = Percent Impervious Area x 0,95		
		- Agriculture	.08	+ Percent Pervious Area x 0.20		
		- Park	.05	+ Percent Semipervious x 0.50		
		- Undeveloped	.00	where		
		Area Range		-impervious means roof, concrete, etc.		
		Numbers	Area (sq. ft.)	-pervious means lawn, open space, etc.		
		1	0-2000	-semipervious means gravel, etc.		
		2	2001-4000			
		3	4001-6000			
		4	6001-8000			

Table 4. Overview of Selected Stormwater Utility Surveys, 1988-1996 (Ungan 1997)

Date	Survey	Range of Population Served	Range of SFR* Charges	Range of Total Utility Revenues (000)	Range of Total Revenues from Charges (000)	Range of Charge Revenues as % of Total Revenues	Range of SFR Charges as % of all Charges
1988	Stormwater Management Adminstration, Maryland Department of the Environment (MDE) (Lindsey, 1988)	20,000-684,565	$1.25-$3.63	$263-$8200	$425-$8200	78%-100%	24%-62%
1990	MDE (Update of 1988 Survey) (Lindsey, 1990)	NA	$1.07-$7.45	$75-10,471	$75-$10,471	82%-100%	15%-78%
1991	The Florida Department of Environmental Regulation (1991)	NA	$1.00-$4.50	$118-$6850	$118-$6850	19% - 100%.	NA
1992	Black & Veatch Communications (1992)	11,000-329,227	$0.24-$9.06	NA	NA	62% - 100%	NA
1992	Apogee Research Inc. (1992)	4,300-535,000	$1 -$4.50	NA	$75-$18,316	8%-100%	NA
1993	Apogee Research Inc. (1994)	NA	$0.24-$9.08	NA	NA	NA	NA

(continued)

Table 4. Continued

Date	Survey	Range of Population Served	Range of SFR* Charges	Range of Total Utility Revenues (000)	Range of Total Revenues from Charges (000)	Range of Charge Revenues as % of Total Revenues	Range of SFR Charges as % of all Charges
1995	Delaware Survey (1995)	6000- 2,000,000	$0.50- $7.16	S19.7- $21,600	NA	NA	NA
1995	Florida Association of Storm Water Utilities (1995)	6000- 2,000,000	$0.50- $7.43	S19.7- $21,600	NA	NA	NA
1996 March	Raftelis (Water and Wastewater Survey) (1996)	NA	$0.15- $10.46	NA	NA	NA	NA
1996 July	Indiana University, Center for Urban Policy and the Environment (Ungan,1997)	11,141- 487,779	$0.24 $10.98	$53- $28,000	$1.8- $28,000	1%-100%	0.7%-92%
1988- 1996	Min: Max::	4300 3,489,779	$0.15 $10.98	$53,000 $28,000,000	$1880 $28,000:000	1% 100%	0.7% 92%

Table 5. Advantages and Disadvantages of Taxes and Charges

Criteria	Charges	Taxes
• Cost of implementation	-	+
• Ease of implementation	-	+
• Deductible by property owner	-	+
• Elasticity of revenues	-	+
• Stability of revenues	+	-
• Fairness		
- user (polluter) pays	+	-
- ability to pay	+	-
- Incentives for on-site controls	+	-

particular property owner will be better off under a charge system than a system of property taxes. It is useful, therefore, to examine the relative burden on property owners under the two systems. Analyses of the relative burden typically show that, to generate a fixed sum of revenues, residential property owners pay less under a user charge system than under a property tax system. Non-residential property owners like owners of commercial and industrial properties typically pay less under a property tax system. For example, to generate $500,000 in Roseville, Minnesota, residential property owners would bear 51% of the burden under a property tax system but only 28% of the burden under a user charge system (Table 6). Similar results have been reported in most jurisdictions where utilities have been considered or established. The main reason is clear: non-residential properties are highly impervious, while residential properties are only moderately impervious, depending on their density. Another reason for the difference in burden is that tax-exempt property owners like churches, hospitals, and school pay charges. For residential property owners, the benefit is partially offset by the fact that charges are not deductible. Nevertheless, they typically are better off under charge systems.

What Are Obstacles To Implementing User Charge Systems?

Stormwater utilities are an attractive source of funds for retrofit programs, and the number of utilities has grown constantly over the past 20 years. Nevertheless, there are a number of obstacles that limit their use. We believe that the main obstacles are economic and therefore political. Many people are opposed to all new taxes, regardless of whether the taxes are perceived as fair. Hence, any time a utility is proposed, property owners will debate the merits of the proposal, and political debate will occur. Two recent cases from Indiana illustrate this point well.

In Vincennes, the Mayor sought new sources of funding to pay for pumps in City Ditch. The Vincennes City Council adopted an ordinance that established a mechanism for allocating charges among property owners in the City Ditch watershed based on parcel-level estimates of runoff volumes. The Council did not, however, pass a companion ordinance to establish a volume-charge. The Mayor lost the next election, and efforts to establish the charge system have foundered.

In Indianapolis, background studies for creating a utility were completed in the 1980s, but no action to establish a utility was taken. In 1997, following endorsement by the Chamber of Commerce, a member of the City-County Council proposed a new utility. The Mayor, who had been

Table 6. Distribution of Property Taxes and User Charges in Roseville, Minnesota (Honchell, 1986)

User/Land Use Category	Utility Charges		Property Taxes	
	Total Revenues	Percent of Revenues	Total Revenues	Percent of Revenues
1 . Residential	$148,000	28.5%	$260,000	50.1%
2. Cemeteries/Golf Courses	$4,000	0.8%	$10,000	1.9%
3. Parks	$10,000	1.9%	–	–
4. Schools	$11,000	2.1%	–	–
5. Apartments/Churches	$44,000	8.5%	$46,000	8.9%
6. Commercial	$302,000	58.2%	$203,000	39.1%
Total	$519,000	100%	$519,000	100%

elected on a pledge of no new taxes, did not endorse the utility, but did not publicly oppose it. Many citizens and some taxpayer groups opposed the proposal, as did some individual members of the Chamber of Commerce. Votes to establish the utility have been delayed because the proposal lacks the necessary number of votes.

These cases are instructive because they demonstrate that proposed new utilities will be controversial even when stormwater problems are long-standing and well known and the proposals are backed by political leaders. In many communities, political leaders are unwilling to endure the high cost of advocating new charges or taxes. Advocates for retrofit programs necessary to achieve water quality objectives must convince political leaders that the benefits of retrofit programs exceed the costs.

Stormwater managers can inform debates through careful analysis. For example, the perceived equity of a proposed system can be enhanced through careful design of the rate structure, including features such as credits for on-site controls. Experience of local jurisdictions that have successfully established utilities demonstrates that there is not a single, correct approach. Innovative applications of basic concepts can help provide funds for retrofit programs.

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Credits as Economic Incentives for On-Site Stormwater Management: Issues and Examples

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Stormwater utilities provide an institutional mechanism for incentives such as credits or reduced user charges in the implementation of onsite stormwater management. Such incentives create greater flexibility by allowing each user to chose the least-cost option—paying the stormwater utility charge or implementing onsite stormwater management. This paper provides examples of stormwater utilities with credits for onsite storm water management, including credits for peak runoff controls, implementation of water quality best management practices, and proper maintenance of onsite stormwater facilities. Also discussed are credits as economic incentives to encourage prevention or reduction of stormwater runoff problems. As economic incentives, credits must be sufficient to induce changes in behavior; however, their impact on total utility revenues must be examined carefully.

Introduction

A stormwater utility is a public utility established to provide stormwater management services. Stormwater utilities, like other utilities, rely on dedicated user charges related to the level of service provided. These user charges are usually based on the amount of impervious area on a property (i.e., a proxy for the estimated amount of runoff discharged from a property). Stormwater utility charges typically are paid by property owners and managed in a separate enterprise fund, which is dedicated to financing local stormwater management services. Most stormwater utilities are administered under public works departments or local departments of utilities that also provide wastewater or water services.

Experience with stormwater utilities has shown that they are capable of generating substantial revenues for local stormwater management programs at relatively nominal charges. Typical monthly charges for residential users range from $2 to around $6 per month. Nonresidential property owners typically pay more because their property is generally larger and developed more intensively.

Stormwater utilities offer three major advantages over financing local stormwater programs from the general fund through property tax revenues. A stormwater utility:

- Provides a dedicated, and stable source of funds for all facets of stormwater management programs (pollution prevention, capital investments, and operation and maintenance);
- Raises funds through charges based on a user's contribution to local stormwater runoff problems an approach often seen as more equitable to rate payers or the public; and
- Provides an institutional mechanism to incorporate incentives (e.g., reduced charges) for implementation of onsite stormwater management.

Overview of Credits as Incentives for Onsite Stormwater Management

The impetus for establishing credits in a stormwater utility rate structure is that a utility may achieve greater flexibility in protecting water quality and aquatic habitat in urban watersheds at a lower overall cost to the community. This greater flexibility can also help a utility lower the total costs of stormwater management for the community. A utility could also reward those users that go beyond minimum requirements in the local stormwater management code, if a credit approach is structured accordingly.

Credits are usually made available only to nonresidential property owners. For utilities where charges to residential properties account for a significant proportion of total revenues, there is less potential for the efficiency gains possible through lowering the total costs of stormwater management.

From an economic perspective, the extent to which a credit will increase the efficiency of a stormwater program depends partly on the conditions in which it applies. For example, if individuals who develop property are not given the option either to build stormwater management facilities and receive a credit or to pay charges and avoid building facilities, then some of the incentive effect is lost. In cases where retrofitting is desired, whether or not a credit will induce property owners to build new stormwater management facilities where none exist or retrofit existing facilities to reduce stormwater charges depends on the size of the charge and the magnitude of the credit.

Examples of Credit (Fee Reduction) Approaches

A recent survey of stormwater utilities (NAFSMA, 1996) asked utilities whether they included incentives, such as reduced user charges, for commercial and industrial properties that implement onsite stormwater management. Of the 38 utilities that responded, 71% (27 utilities) had no fee reduction. Of the remainder of (11 utilities), two major types of fee reduction approaches were reported: 16% (6 utilities) had fee reduction for peak runoff controls, and 8% (3 utilities) had fee reduction for implementation of water quality best management practices or proper maintenance of onsite stormwater facilities. An earlier report on stormwater utilities (USEPA, 1992) found over 20 utilities with various types of credits as incentives for onsite stormwater management.

Some stormwater utilities offer credits for onsite stormwater detention/retention facilities in new developments. Credits can also provide incentives for onsite stormwater detention/retention through retrofitting older dry detention basins to extended detention basins or controlling peak flows through rooftop or underground storage tanks. Examples of credit approaches for selected utilities are highlighted below and summarized in Table 1.

Gainesville, Florida

The City of Gainesville's Stormwater Management Utility provides reduced monthly fees for nonresidential properties with privately maintained, onsite stormwater management retention systems. The maximum allowable credit is 100% of the utility's "base" fee, which is based on the amount of impervious area and one-half of pervious parking areas. The percentage of fee credit is determined by the volume of onsite retention provided (detention volume is not considered since that stormwater is discharged). The required volume is determined by the 25-year, 24-hour storm. Most credits range from 15 to 35%.

Orlando, Florida

In the City of Orlando, the stormwater utility provides a lower rate for commercial and multi-family residential properties with onsite stormwater management facilities. Such properties with approved onsite retention or detention get a credit on the rate charged per ERU (equivalent residential unit). The typical rate is $66.00 per ERU. The lower rate for properties with approved onsite stormwater facilities is $38.28 per ERU. Overall, this provides a 42% credit on the stormwater utility fee.

Wichita, Kansas

The City of Wichita's Stormwater Utility offers credits only for properties with 50 or more equivalent residential units. Two credits on the drainage fee are available. First, up to 40% credit on the fee is available for detention that equals or exceeds the city's new development standards (based on 100-year design storm). Second, an 80% credit on the fee is available for retention (no runoff from site). No credits are being given because the stringent standards are difficult to achieve.

Louisville & Jefferson County Metropolitan Sewer District, Kentucky

Credits are provided primarily for commercial properties with onsite detention for control of peak flows in the Louisville/Jefferson County Metropolitan Sewer District (MSD). A range of credits is available depending on how the detention basin functions. Basins must be sized for the 2-year, 10-year, and 100-year storms and also limit discharges to the pre-development rate of runoff. Credits are available for each type of storm, with an 82% maximum credit if all criteria are met. MSD is currently evaluating how to incorporate stormwater quality measures into its credit approach.

St. Paul, Minnesota

The City of St. Paul provides a rate of discharge credit for nonresidential properties on its storm sewer system charge. For nonresidential properties, this charge is based on actual parcel acreage and a standardized peak runoff rate determined for selected land use classifications. Where the peak stormwater runoff rate is limited by onsite facilities such as detention ponds owned and maintained by the property owner, up to a 25% credit is available. A 10% credit is provided for parcels that provide onsite storage for the 5-year design storm that also limit its discharge to a maximum of 1.64 cubic feet per second per acre. An additional 15% credit is provided for parcels that provide onsite storage for the 100-year design storm that also limit its discharge to a maximum of 1.64 cubic feet per second per acre. Both new developments and redevelopment are eligible for apply for credit. Existing nonresidential properties can retrofit to provide onsite storage for the 5-year design storm and get the 10% credit. Most credits were provided in the first few years after the credit approach was established. Currently, around 3-4 credits are approved annually. In St. Paul, the credit approach increased the political acceptability of the storm sewer system charge.

Charlotte, North Carolina

The City of Charlotte provides one or more credits for commercial, industrial, institutional, and multi-family residential properties and residential homeowner associations that mitigate the impacts of runoff on the stormwater system. Eligibility for one or more credits to the service rate

Table 1. Summary of Credit Options

Utility	Eligible Users	Basis for Credit	Design Storm	Maximum Credit	Typical Credit
Gainesville, FL	Nonresidential	Volume of onsite	25-year, 24-hour storm	100% of base fee	15-35%
Orlando, FL	Commercial and multi-family residential	Onsite retention or detention	NA	42%	42%
Wichita, KS	Properties ≥ 50 ERUs	Two credits: volume of detention or retention	1) 100-year storm 2) Complete retention	1) 40% 2) 80%	Currently no applications
Louisville-Jefferson County, KY	Commercial properties	Onsite detention of peak flows	2-year, 10-year, 100-year storms; pre-development runoff	82%	Varies with degree of control
St. Paul, MN	Nonresidential properties	Onsite detention of peak flows; acreage, peak flows	5-year, 100-year storms; release limited to 1.64 cfs/acre	10% (5-year storm) 25% (100-year storm)	Varies with degree of control
Charlotte, NC	Commercial, industrial, institutional, multi-family residential; homeowner association	1) peak discharge 2) total runoff volume 3)annual pollutant loading reduction	1) 10-year, 6-hour 2) 2-year, 6-hour 3) reduction in loading	1) 50% 2) 25% 3) 25% Up to 100%	Varies with degree of control
Durham, NC	Nonresidential properties	Pollution credits for Water quality and quantity controls	State standards for facility design; estimated pollutant removal efficiency	25%	Few applications
Cincinnati, OH	Commercial properties	Onsite retention	Limit discharge to pre-development runoff	50%	Credit never used
Tulsa, OK	Privately maintained facilities	50% greater detention; maintenance costs of onsite facilities		60%	Varies
Austin, TX	Commercial properties	Onsite detention, inspection		50%	50%
Bellevue, WA	All properties	Onsite detention; intensity of development		Reduction of one rate (intensity of development) class	Varies
King County, WA	Commercial properties	Private maintenance		Reduction of one rate class	Varies
Indianapolis, IN	Nonresidential properties	Discharge to specified streams; onsite retention or detention watershed size	Tier Two:2-, 10-, 25-, 50-, 100-year events	Tier One: 25%; ≤$50 Tier Two: 35%; <$250	(proposed)

charge is proportional to the extent those stormwater management measures address the impacts of peak discharge, total runoff volume, and annual pollutant loading from the site. Portions of the service rate charge are available for credit as follows: up to 50% for reducing peak discharge from a 10-year, 6-hour storm; up to 25% for reducing total runoff volume from a 2-year, 6-hour storm; and up to 25% for annual pollutant loading reduction. Each credit allowed against the service charge is conditional on continued compliance with the Charlotte Mecklenburg Land Development Standards Manual and may be rescinded for noncompliance with those standards. If 100% credit is given, the affected property will receive no stormwater service charges.

Durham, North Carolina

The City of Durham provides up to a 25% pollution credit on the stormwater utility fee for selected structural stormwater controls on nonresidential properties. Currently, the maximum pollution credit goes to standard basin designs that are identified as achieving maximum pollutant removal efficiency in state performance standards. For other structural controls in the state's standards, the city's pollution credit will be linearly variable, with no credit given for a removal efficiency of 0% of total suspended solids to a 25% credit for a removal efficiency of 85% of total suspended solids. The city recently approved sand filters in addition to the approved onsite basin designs, but no pollution credits are established yet for sand filters. Durham receives few applications for credits.

Cincinnati, Ohio

The City of Cincinnati's Stormwater Management Utility offers a credit for commercial properties that install onsite retention that goes beyond normal building requirements (i.e., limit discharge to pre-development level of runoff). Such properties can apply for a credit of up to 50% on the utility's storm drainage service charge. This credit has never been used in Cincinnati.

Tulsa, Oklahoma

Under the City of Tulsa's stormwater drainage system service charge, credits are provided for private maintenance of approved onsite detention or retention facilities. An approved onsite facility must provide at least 50% more detention than required by the city. The amount of credit varies based upon the estimated maintenance costs if the city were providing the maintenance. The maximum credit is 60% of a property's annual stormwater charge. This maximum was established at 60% because around 60% of the stormwater utility budget in Tulsa goes to maintenance. Upon inspection, if an onsite facility is not performing adequately, then the property owner must pay the typical stormwater drainage service charge.

Austin, Texas

The City of Austin's Drainage Utility provides a 50% credit on the drainage fee for commercial property owners that construct and maintain approved onsite detention facilities. The city inspects these onsite facilities annually to ensure proper maintenance.

Bellevue, Washington

The City of Bellevue Storm and Surface Water Utility provides a credit on its storm and surface water drainage service charge for approved onsite detention facilities. This credit has worked well to get approved detention facilities built on large residential and commercial plats. Bellevue's utility rate structure classifies each property according to its percentage of developed property (from undeveloped land to very heavy development). A reduction of one intensity of development classification is provided for installation and maintenance of approved onsite detention facilities. This reduces the rate (based on the intensity of development classification) and the storm and surface water drainage service charge for such properties.

King County, Washington

Under the new King County Surface Water Drainage Design Manual, any development of parcels with over 5,000 square feet of impervious area must provide onsite detention/retention. For commercial properties, King County provides a credit through a reduction of one rate classification for the utility fee for private maintenance of an approved onsite detention/retention facility. The facility must be built to code and meet King County maintenance standards.

Issues in Establishing Credits for Onsite Stormwater Management

Like stormwater utility charges, there is no "correct" method for establishing credits. Each utility must consider local stormwater management goals in deciding whether to incorporate such incentives into their utility rate structure. The amount of impervious area on a property is usually the basis for stormwater utility charges. The quantity of stormwater runoff is generally the rationale behind charging property owners for stormwater management services (e.g., a user-pay approach). The adverse environmental impacts of urban runoff are related to both stormwater quality and quantity. To date, few stormwater utilities have attempted to incorporate measures of the quality of runoff as a basis for utility charges. Additionally, few utilities incorporate site characteristics other than impervious area (e.g., slope and soil characteristics) that also influence the adverse impacts of runoff. These factors may be important in setting charges and credits to induce the expected behavior of choosing the least-cost option. On the other hand, if stormwater quantity (as measured by the amount of impervious area) is closely correlated with adverse impacts of runoff related to both stormwater quantity and quality, the amount of impervious area may be a sufficient basis for setting charges that create the desired incentives.

Although credits must be sufficient to induce changes in behavior, their impact on total utility revenues must be examined carefully. An approach that gave large credits for onsite stormwater management could significantly reduce revenues for a local stormwater management program. Each community should evaluate whether charges and credits proposed for its utility are likely to promote onsite stormwater management and whether mechanisms are in place to ensure that onsite stormwater management achieves the desired environmental results.

Finally, public acceptability and political support is important to establishing a utility rate structure, whether or not it includes a credit approach. The nature of local government is that key players in utility design and implementation are seldom the key players in local politics. In designing a credit approach, a utility can attempt to minimize controversy by developing education and involvement programs for informing and gaining the support of local government officials and the public.

Case Study of Issues Associated with Proposed Credits in Indianapolis, Indiana

The City of Indianapolis is currently attempting to design a credit approach for its proposed stormwater utility. Considerable controversy has arisen over the proposed utility and a credit system is under consideration in part to help overcome general opposition to new charges or taxes. Through a credit system, utility planners and local elected officials are attempting to make the proposed stormwater utility charges more equitable and acceptable politically. The credit system in the most recent draft ordinance (Proposal No. 657, 1997) is a relatively complex approach to provide a reduction in stormwater user fees for nonresidential properties based on 1) certain qualifying conditions (location in relation to a major waterway), 2) activities that mitigate the impact of increased stormwater runoff from a property on a continuing basis, or 3) activities that reduce the city's cost of providing stormwater management services to a property. The draft ordinance outlines a two-tiered credit that is based on watershed area as well as the size of the onsite detention/retention basin. The city will also develop a proposed Storm Water Credit Manual for use in reviewing and acting upon applications for credit. A credit application fee is also authorized in the draft ordinance. Efforts to establish a credit system for onsite detention/retention have addressed concerns of property owners and generally increased the perceived fairness of the proposed rate structure, and it is clear that the proposed utility could not be adopted without some type of credits. Inclusion of a credit system, however, has not been sufficient to ensure adoption of the stormwater utility and overcome other objections.

Conclusion

Economists have long advocated pollution charges as an approach to achieve greater flexibility and efficiency in pollution control. If such charges are set to reflect the environmental damage actually caused by polluted discharges, economic theory suggests they can create incentives for each user to choose the least-cost option—paying a pollution charge or implementing pollution control requirements. Making credits available on stormwater utility charges for implementation of onsite stormwater management can create comparable incentives for users and potential efficiency gains by lowering the total costs of a stormwater management program. Additional research is needed to evaluate the efficiency and equity issues associated with credits and stormwater utility charges. Until the economic and data issues in establishing a credit approach are better understood, communities considering a credit approach should examine the experience of those utilities that have implemented credits to evaluate whether such approaches are appropriate for local stormwater management goals and problems.

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Conservation Design for Stormwater Management

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Background

The State of Delaware has developed a manual to provide guidance for site design which incorporates conservation into land development (DDNREC and BC, 1997). The intent is to provide an incentive for land developers to retain and incorporate existing natural site features into the site development process and thereby reduce or eliminate the need for structural stormwater management controls. Other benefits are certainly realized through Conservation Design, such as more closely approximating the predevelopment water budget, protection of habitat, and reduced overall impact to the receiving system. Site features discussed in the manual include:

- Wetlands
- Floodplains
- Forested areas
- Meadows
- Riparian buffers
- Soils
- Other natural features

Design procedures are provided which allow site designers to incorporate practices inherently known to be good, but which have not had the detailed design guidance that ensures plan approval. That guidance is provided in the manual for a variety of situations. The design approach is flexible enough to allow for various conservation practices to be combined on one site and to quantify the benefits of that combination.

It must be emphasised that structural controls will still be essential on many sites. A heavily wooded site having a significant portion of the tree canopy removed will still have a significant increase in stormwater runoff, even with aggressive conservation planning. The practices detailed in the manual are provided as additional tools in the stormwater management toolbox. They supplement structural control practices and may, in some situations, eliminate or reduce the need for structural practices while providing attractive site amenities.

Limitations of Structural Stormwater Management

Most stormwater management programs place a heavy reliance on implementation of structural stormwater management facilities. These facilities include ponds, both wet and dry; infiltration; filtration; and other variations of them all. The implementation of these facilities is necessary for their water quantity and water quality benefits and is expected to remain integral to program implementation, but there should not be an overreliance on them. These practices, in and of themselves, cannot eliminate adverse impacts of urban development. In addition, there are a number of limitations to structural facilities.

A stormwater management program relying solely on structural practices has a number of weaknesses.The existence of these weaknesses has been recognized for some time, but there has been little information available on alternative approaches that would justify their inclusion in a stormwater management program. The following items present some of the weaknesses.

- Lack of flexibility in site design
- Altered site hydrology
- Expense
- Loss of site area
- Potential increased impacts to site and watershed natural resources
- Configuration of development
- Connection of impervious areas
- Disregard of site resource conservation benefits
- Maintenance obligations

Conservation Design Approaches

Conservation Design approaches reflect a totally different philosophy towards site design which integrates stormwater management into the very core of site design, as opposed to an afterthought. These approaches can include an almost endless universe of practices, strategies, planning, and common sense. The manual doesn't include all potential components, but provides guidance and information on many that are currently recognized where data exists or can be generated to substantiate their benefits from a water budget perspective.

It is important to develop a conservation ethic which treats stormwater runoff as a "resource" rather than a "byproduct" of development. As such, there are a number of key site design components to consider:

- Reducing impervious surfaces
- Constructing biofiltration practices
- Creating natural areas
- Leaving areas undisturbed
- Clustering development

Conservation approaches are discussed throughout the manual, but some are briefly discussed here to provide an initial awareness of the range of options that will be discussed later in greater detail. Examples of conservation approaches include the following.

Reducing Impervious Surfaces

Impervious surfaces (roads, roofs, sidewalks) prevent the passage of water through the surface into the ground. Water must then be transported across the surface to a point of discharge. <u>Reducing the total amount of imperviousness is the single most important conservation tool available</u>. Residential subdivisions can reduce the width of roadways, or design the roadways to limit the total length needed to service individual properties. Roof downdrains should not be directly connected to streets when providing splash blocks, but should discharge the water away from impervious surfaces (sidewalks, streets) to allow for a greater amount of water to infiltrate into the ground.

Just as important in limiting impervious surfaces and separating roof drains from direct connection to streets is the need for education of homeowners regarding their responsibility to ensure continued function of these practices. Homeowners often change the orientation of downspouts or otherwise redirect lot drainage to impervious surfaces which undoes a lot of conservation benefits. Community education and involvement is integral to effective program implementation.

Constructing Biofiltration Practices

The use of vegetative swales and buffer strips can provide a significant water quality benefit in addition to reducing the total volume of stormwater runoff. The primary processes involved in their performance are filtering of pollutants contained in stormwater runoff, and infiltration of runoff into the ground.

Even where curbs are needed to restrain traffic movement to paved surfaces, curb cuts or openings can be placed to allow water to pass off of the paved surface into a biofiltration facility. This would allow for both public works and stormwater objectives to be attained.

Creating Natural Areas

In many site development situations, the predevelopment condition may be farmfield or other disturbed condition. Creation of a meadow as open space would have significant stormwater management benefits for both water quantity and water quality. The area, if well designed and constructed, could become an attractive amenity to a community and enhance the value of the properties.

Leaving Areas Undisturbed

Many sites have existing resources which, in addition to other values, have stormwater management benefits. These natural systems include forested areas, wetlands, and other areas of natural value such as meadows.

Forested areas provide for rainfall interception by leaf canopy. In addition, an organic "duff area" develops on the woodland floor which acts very much as a sponge to capture the water and prevent overland flow. In addition, trees use and store nutrients for long periods of time. Trees also moderate temperatures during the summer and provide wildlife habitat, thus providing other environmental benefits.

Wetlands are valuable resources and provide numerous benefits including flood control, low streamflow augmentation, erosion control, water quality, and habitat. They are very productive ecosystems whose maintenance would have significant water quantity and quality benefits. Where they exist on a land development site, they could become an important element in site design.

Cluster Development

How a site is developed and to what degree the entire site is utilized will have a significant impact on stormwater runoff from the site. Conventional land development encourages sprawl, while innovative approaches to land development can provide significant stormwater benefits. Cluster development encourages smaller lots on a portion of a site, allowing the same site density, but leaving more site area in open space. Clustering designs residential neighborhoods more compactly, with smaller lots for narrower single-family homes, found in traditional villages and small towns. Cluster development can provide for protection of site natural areas, while at the same time reducing total site imperviousness by reducing the areal extent of roads.

The Conservation Design Procedure in Detail

Conservation Design can be thought of as a series of questions which must be asked as it is applied to each site. If site designers rigorously address all of these questions, the Conservation Design procedure will have been accomplished, and the "answers" will be successfully identified for each site. The overriding objective is to achieve a new way of thinking about site design.

The procedure has been kept simple by intention. It is grounded in effective and complete site analysis, and an upfront commitment by the site designers to inventory and evaluate the various "systems" which define the site and which pose problems as well as opportunities for site development. The more clever the development "tinkering" can be, the more successful Conservation Design can become. Extra effort up front pays important dividends in the long run. Conservation Design requires a major departure from the conventional mindset of stormwater disposal - which is a reactive end-of-the-line process forcibly imposed onto a development program. Conservation Design is proactive in the best sense of the word, based on understanding natural system opportunities which enable us to integrate essential stormwater quality and quantity management objectives into the devlopment design from the very beginning.

Rather than provide a lengthy discussion of conservation design procedures, this paper provides a checklist of items or "questions" which should be considered in conservation design. Those questions are listed as follows:

1. Site Analysis Background Factors: How do Background Site Factors Affect the Conservation Design Process?

   Hydrologic issues:
   - Is the site tidally dominated?
   - Does the site flow to special waterbodies with special water quality needs?
   - Are there known downstream flooding problems?
   - The site is located in what watershed?
   - Does the site discharge into 1st, 2nd, 3rd order streams?
   - Is the site in the upper, middle, or lower part of the watershed?

2. Site Analysis Site Factors Inventory: What Site Physical Factors Affect Conservation Design?

   Site size and shape:
   - Does site size limit Conservation Design?
   - Does site shape or other factors limit Conserva tion Design?

   Natural features:
   - What is the basic site hydrology?
     - Perennial streams?
     - Intermittent swales?
   - Describe site soils
   - Describe site vegetation
   - Describe site critical features:
     - Do wetlands exist?
     - Are there floodplains?
     - Are there riparian areas?
     - Are natural drainageways present which are not perennial streams per se?
     - Are there special habitat areas?
     - Do special geological formations exist (i.e., carbonate)?
     - Do steep slopes exist?
     - Are there high water table, bedrock, other limitations?

   Built/developed features:
   - Does the site have centralized sewer?
   - Does the site have centralized water?

3. Site Factors Analysis: What Site Factors are Constraints and Opportunities in terms of Conservation Design?

   Site Constraints:
   - Where should building and roads be avoided?
     - In terms of vegetation?
     - In terms of soils?
   - Are any areas off limits for all forms of disturbance?

   Site Opportunities:
   - Where does most recharge occur?
     - In terms of vegetation?
     - In terms of soils?

4. Building Program: How do Building Program Factors Enter into the Conservation Design Procedure?

   Can the proposed building program be reduced in terms of total number of units?
   Can the type of units be modified (e.g., from single-family to townhouse)?
   What is existing site zoning?
   Are zoning options allowed?
   Have building setbacks been made to be flexible?
   Have innovative development concepts such as zero lot line or clustering been considered?
   What does the comprehensive plan indicate for the site and adjacent areas?
   What are the adjacent land uses?
   Other Management/Regulatory issues:
   - What municipal/county requirements exist for stormwater?
   - Will some aspects of Conservation Design require waivers?
   - What other municipal/county requirements exist for land development?
   - Will some aspects of Conservation Design require waivers?

5. Lot Configuration and Design: How Can Lot Configuration and Overall Site Design Prevent Stormwater Generation?

Have lots been reduced in size to the maximum degree?
Have lots/uses been clustered/concentrated to the maximum degree?
Have lots been configured to avoid critical areas?
Have lots been configured to take advantage of effective Conservation Design mitigative practices?

6. Impervious Coverage: Have Impervious Surfaces Been Reduced as Much as Possible?

   Have road lengths and widths been reduced to the maximum degree?
   Have driveway widths and lengths been minimized to the maximum degree?
   Have parking ratios and parking sizes been reduced to the maximum extent?
   Has potential for shared parking been examined fully?
   Have cul-de-sacs and turnarounds been designed to minimize imperviousness?
   Have sidewalks been designed for single-side movement?
   Can porous surfaces be used for overflow parking, low impact shoulders, other applications?

7. Minimum Disturbance/Maintenance: Has Disturbance of Site Vegetation and Soils Been Minimized?

   Has maximum total site area, including both soil and vegetation, been protected from clearing and any other type of development disturbance?
   Are zones of open space maximized?
   Do these open space zones make sense internally, externally?
   In terms of individual lots, has maximum lot area, including both soil and vegetation, been protected from clearing and other development-related disturbance?
   Do structures correspond to site features such as slope, in terms of type of structure, placement on lot, elevation, and so forth?
   Have revegetation opportunities been maximized throughout the site?
   Have revegetation opportunities been maximized in critical areas such as riparian buffer zones?

8. Use of Mitigative Conservation Design Practices: Which Practices are Most Effective and How Can Their Positive Effects be Maximized?

   Are vegetated swales with check dams being used?
   Are vegetated filter strips with level spreading devices being used?
   Are berms and other terraforming technique being used in conjunction with zones of natural vegetation?

9. The Conceptual Stormwater Management Plan: How Can All Preventive Approaches and Mitigative Techniques be Integrated into an Optimal Conservation Design Plan?

   How has the stormwater plan been integrated into the overall site design?
   Has prevention been maximized through Conservation Design Approaches?
   Has mitigation been maximized through Conservation Design Practices?
   What other benefits are achieved through Conservation Design (i.e., open space, enhanced marketability, cost reduction, habitat protection, stream water temperature, biota impacts, other stream impacts?)

10. Stormwater Calculations: How Has Conservation Design Affected Stormwater Calculations? What Conventional Stormwater Techniques are Necessary to Manage Any Residual Stormwater Need not Mitigated by Conservation Design?

    How has impervious cover been reduced?
    What are the implications for Curve Numbers?
    How have total runoff volumes been affected?
    Has time of concentration been maximized?
    How has peak discharge rate been affected?
    How has recharge volume been affected?

11. Selection of Additional Stormwater Controls: If Conservation Design has not Fully Met all Stormwater Requirements, What Additional Requirements Must be Provided?

Watershed Wide Approaches

While not a focus of the manual, watershed-wide considerations are important and should be the context from which many resource-based land development decisions are made. The manual strongly supports watershed-based approaches to land use decisions. This context is important from a number of perspectives.

- Watershed approaches allow for a recognition and consideration of where growth distribution should occur.
- Consideration of land use from a watershed perspective allows for a greater awareness of the cumulative impacts of watershed development.Impervious surfaces are important to consider if downstream areas are to be protected.
- A comprehensive approach to resource protection can be developed and implemented based on consideration of watershed specific issues such as steep slopes, high water table, the need for aquifer recharge, etc.
- A watershed approach allows for developers and the general public to understand the basis by which land use decisions were made in a rational format which can be easily understood.
- Land use decisions based on watershed-wide analyses provide the local government with a basis for making land use decisions that can be defended.

As desirable as watershed-wide approaches are, it must be recognized that significant resources and costs may be needed to accomplish those efforts. Depending on the goals of the effort, significant data needs may exist.

Conclusion

Over the past 20 years, stormwater management has evolved from water quantity control, to water quality control, to attempting to address stream ecology. What has become apparent is that traditional end-of-pipe controls such as ponds do not provide the level of protection necessary to protect in-stream resources. We have gone full circle in again having to consider water quantity, but this time not just to reduce downstream flooding concerns. The total volume of water running off the land, in addition to riparian buffer protection, becomes critically important.

Site features, as mentioned in the abstract, must be considered integral to site development. Too often we have totally reconstructed a landscape for an individual's economic benefit only. We must recognize the economic and resource impacts that occur downstream from sites being developed.

There are ways to develop sites and protect or enhance existing resource values. It is not rocket science. If we as a society consider conversion of land to urban use as a desirable societal product, we must do more than accept the adverse impacts that those site activities cause. We can minimize adverse downstream impacts if greater weight is given to existing site resources. In many situations, as shown in case studies, land can be developed, less expensively using greater protection of existing site resources, than when using a conventional approach.

The choice is ours.

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Results of the Site Planning Roundtable

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The Site Planning Roundtable, originally convened by the Center for Watershed Protection in October 1996, brought together representatives from various national planning organizations, development and environmental communities, and local government. The goal was to provide the technical, professional, and real-world validation required to promote environmentally sensitive, locally relevant, and economically viable development. In line with this goal, the Roundtable has developed a set of 22 Model Development Principles that aid local planners and zoning officials in identifying how existing ordinances can be modified to reduce impervious cover, provide effective stormwater treatment, and conserve natural areas. These principles are not national design standards. Instead, they identify areas where existing subdivision codes can be changed to better protect streams, lakes and wetlands at the local level.

Conventional zoning standards outline minimum lot areas, setbacks, frontages, and road widths, often resulting in significant impervious cover in the form of wide streets, expansive parking lots, and large-lot subdivisions. Planners, landscape architects, and developers can utilize a wide range of innovative site planning techniques to reduce imperviousness at the site level. In some cases, full utilization of these techniques requires changes to outdated zoning regulations or inflexible subdivision codes. The Model Development Principles focus on changing these regulations and codes. Each principle presents a simplified design objective; techniques for achieving the objective should be based on local conditions.

Residential Streets

An important objective of the Site Planning Roundtable effort was to identify practical and cost-effective strategies to overcome barriers to implementation of the Model Development Principles. One particular area of concern emerged: residential road width. Most local governments model their residential street design standards upon state and/or federal highway criteria, although the traffic capacity and function of residential streets differ considerably from that of highways. Consequently, residential street widths tend to be wide rather than narrow. Efforts to reduce road widths are often met with strong opposition on a variety of fronts. Local planners and engineers are reluctant to modify standards due to safety concerns. Public works officials wish to maintain adequate access for emergency, service, and maintenance officials. Residents voice concerns about impacts to parking.

The following discussion will present alternative design standards to reduce imperviousness and demonstrate how many of the impediments to narrow streets are already being overcome with careful site design.

Perceptions and Realities: Parking Demand

Why are residential streets wide? Parking is a major factor. On-street parking on both sides of the street can increase site imperviousness by approximately 25% (Sykes, 1989). Limiting parking to one side of the street or the use of queuing lanes can significantly reduce this imperviousness. The reduction of on-street parking is often cited as an impediment to narrow streets. This impediment can be overcome. In Portland, Oregon, parking is accommodated through the use of “queuing streets” which are 20’ or 26’ wide (Figure 1).

Perceptions and Realities: Safety

The potential for increased vehicle-pedestrian accidents is an often cited reason for prohibiting narrow streets. Many studies, however, indicate that narrow streets may actually be safer than wider streets. The Federal Highway Administration (1996) noted that narrow widths tend to reduce the speed at which drivers travel, providing greater driver reaction time. Further, in a study of over 5000 pedestrian and bicycle crashes, a narrow road was a factor in only two cases (FHWA, 1996). Unsafe driving speed, on the other hand, contributed to 225 accidents.

Case Study: Longmont, Colorado

The City of Longmont, Colorado, is experiencing rapid growth. The quality and type of new development has become an important issue as more development and nonconventional site designs are proposed. Part of this discussion involves acceptable residential street design. Swift and Associates (1998) examined over 20,000 police reports to determine the relationship between street design

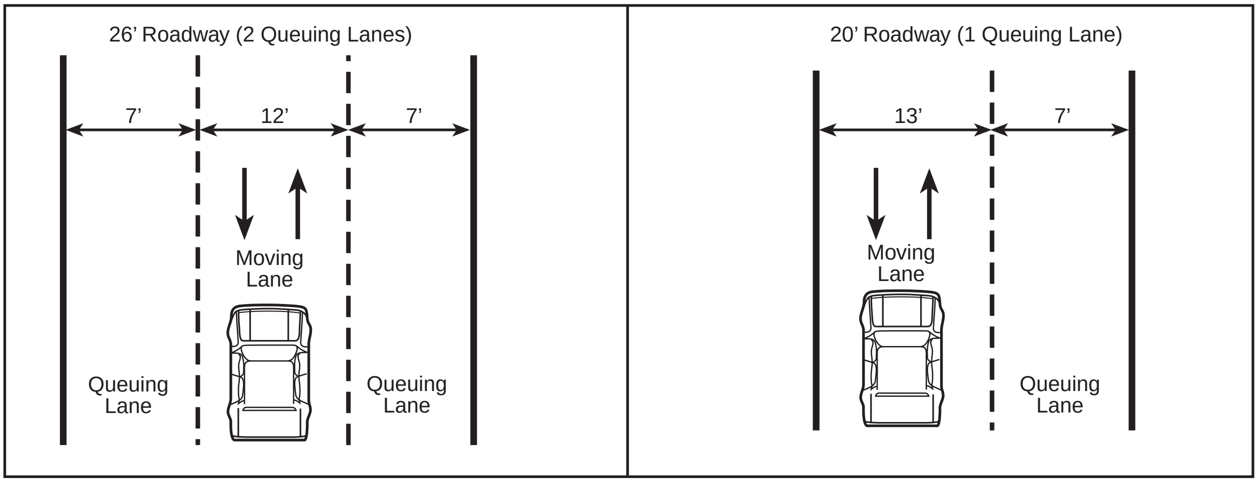

Figure 1. Queuing Lanes in Portland, Oregon.

and safety. The study focused specifically on residential streets with maximum average daily traffic (ADTs) of 2,500. Accidents attributable to poor road conditions or substance abuse were excluded from the study. The results of the Longmont study indicate that in general, narrow, curved streets can be safely used in residential developments. Specifically, streets between 22 to 30 feet in width were found to be the safest (see Figure 2).

Perceptions and Realities: Adequate Access

The conventional wisdom is that very wide streets are needed to provide adequate access for emergency, service and maintenance vehicles. But the facts do not support this concern:

- Trash trucks require only a 10.5' travel lane (Waste Management of Montgomery Count, 1997), with a standard truck width of approximately 9' (BFI of Montgomery County, 1997).
- Half-ton mail trucks, smaller than many privately owned vehicles, are generally used in residential neighborhoods. Hand delivery of mail is also an option (US Post Office, 1997).
- School buses are typically nine feet wide from mirror to mirror. Many jurisdictions require only a 12' driving lane for bus access.
- Snowplows, mounted on pick-up trucks, with 8' width, are common. Some companies manufacture alternative plows on small "Bobcat" type machines (Frink America, Incorporated 1997).
- A number of local fire codes permit roadway widths as narrow as 18' (Table 1).

Narrow Streets

Reduced pavement widths can significantly reduce the impervious impact of residential developments. Site designers should consult with public works, emergency service, and residents to confirm that the community's needs are met. Adequate access, parking, and safety can be ensured through careful site design.

In addition to environmental benefits, significant construction cost savings can be achieved by building narrower streets. Pavement construction costs are approximately $15 per square yard. Suppose, for example, that a local jurisdiction currently requires all residential streets with one parking lane to be a minimum of 28 feet wide. The jurisdiction then adopts a new standard: 18 feet wide queuing streets. This new standard would reduce the overall imperviousness associated with a 300-foot road by 35% and construction costs by $5,000. Additional economic benefits include reduced clearing and grading costs and reduced long-term pavement maintenance costs.

Acceptance of the narrow streets design requires implementation as a flexible, locally adapted strategy. Therefore, the Model Development Principles must be consistent with the larger community goals (both economic and environmental) that are put forth in comprehensive growth management, resource protection, and watershed management plans. Finally, the Site Planning Roundtable encourages local, state, and federal agencies to provide the technical support, financial incentive, and regulatory flexibility needed to promote and implement the Model Development Principles, and to fundamentally change the way development takes place.

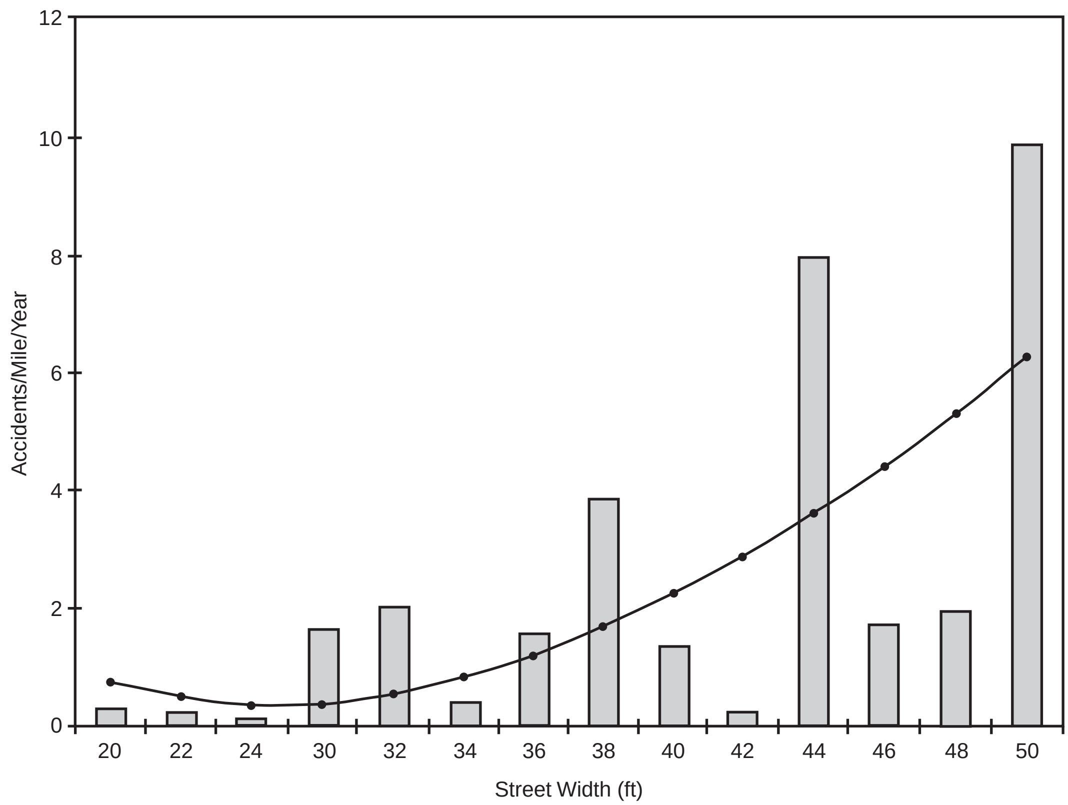

Figure 2. Relationship between street width and accidents in Longmont, Colorado, based on Swift and Associates (1998).

Table 1. Street Width Requirements for Fire Vehicles

Width	Source	Comments
18-20’	US Fire Administration (Cochran,1997)	Represents typical “fire lane” width
24’ (on-street parking) 16’ (no on-street parking)	Baltimore (MD) County Fire	Road width
18’ minimum	Virginia State Fire Marshal	Road width
24’ (no parking)	Prince Georges County (MD) Department of Environmental Resources	Road width
30’ (parking on one side) 36’ (parking on both sides)		
20’	Prince Georges County (MD) Fire Department	Road width

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Retrofitting Conservation Designs into the Developed Landscapes of Northeastern Illinois

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Abstract

There is a small but growing trend to retrofit developed landscapes in northeastern Illinois with more environmentally friendly designs. The motivation for these activities varies from site to site. Commonly, those initiating retrofits are hoping to reduce landscape maintenance costs, fix erosion problems, improve water quality, enhance aesthetic conditions, and/or reduce flooding.

Four types of retrofitting have been identified. Retrofitting conventional turf landscapes with native prairie/wildflower vegetation is one of the more visible and exciting trends. Notably, prairie landscaping has become a desirable option for several high-visibility corporate, school, and government campuses. Stream channel retrofitting also has become common. Many of the recent stream projects have been stimulated by demonstration projects, funded through Section 319 of the Clean Water Act, to reduce bank erosion. Detention retrofitting has been done on a more limited scale. Detention basin retrofitting has been initiated to improve stormwater runoff control, reduce shoreline erosion, improve aesthetics, and limit excessive Canada goose populations. Conversion of storm sewers to open drainageways has been performed on a very limited basis to improve treatment of runoff pollutants.

While water quality has not been the principal impetus for many of the recent retrofit projects, the water quality benefits can be substantial. As a consequence, watershed managers are increasingly recommending large-scale retrofitting to enhance the beneficial uses of urban and suburban waterbodies and are selling the retrofit concept on aesthetic and cost-saving grounds.

Motivation for Retrofitting

From a water resources perspective, there is a growing realization that the developed landscape of northeastern Illinois has some serious design and performance flaws. One of the most obvious reminders of this fact is the frequent and increasing incidence of damaging floods. Where there was once considerable ignorance regarding the causes of flooding, the average resident can now readily relate local and regional flooding to new roads, parking lots, and subdivisions and their contributions of increasing stormwater runoff.

Similarly, but to a lesser degree, there is an increasing awareness that conventional urban development designs have led to impaired water quality and degraded recreational uses of waterbodies. Contributing factors include polluted stormwater runoff and the outright destruction of wetlands and riparian corridors.

Increasingly, concerns also are being raised about the sustainability of traditional development. In particular, individuals are questioning the costs of maintaining both the structures and the landscapes that dominate the developments of the recent past. In particular, questions are being raised about the continued reliance on turf grass as the dominant landscaping material for commercial, office, and residential developments. There are concerns about the expense and environmental impacts of a maintenance approach that relies on frequent mowing, irrigation, and the extensive use of chemicals for fertilization and pest control.

Fortunately, there is also a growing awareness and appreciation of an alternative urban design ethic that incorporates “natural” elements into developed properties. This alternative ethic is based on both ecologic and aesthetic considerations. Central to this ethic is the belief that it is both possible and desirable to commingle natural areas and materials with developed landscapes. Elements of this ethic include use of native plants for landscaping, preserving or restoring natural buffers at the edges of developments, and incorporating native ecosystems — prairies, wetlands, and woodlands — into development site designs.

Cumulatively, this growing awareness of the shortcomings of conventional design and the potential benefits of naturalistic approaches provide the basis and motivation for retrofitting elements of the developed landscape.

Types of Retrofitting

Retrofitting, as described in this paper, includes a range of activities. In other contexts, some of these activities might be termed rehabilitation, restoration, or renovation. Regardless of terminology, retrofitting is assumed to involve a substantive, long-term change to an existing facility or landscape resulting in demonstrable improvements to water quality and aquatic ecosystems.

Four types of retrofitting projects have been implemented in northeastern Illinois and are documented in this paper. They are:

- converting conventional turf landscapes to native vegetation,
- restoring eroding and/or channelized stream and rivers,
- retrofitting stormwater detention basins, and
- converting, or "daylighting," storm sewers to open drainageways.

Converting Turf to Natural Landscapes

For decades, exotic turf grass has been the dominant landscaping material for almost all new development in the region. Considering that the pre-development landscape on most sites is cropland, and considering the relative paucity of remnant native landscapes such as prairies, savannas, and woodlands, this landscaping philosophy is not surprising. Recently, however, there has been growing and enthusiastic support for *natural landscaping*, an alternative approach that utilizes native plants that are adapted to the local climate and soil (Northeastern Illinois Planning Commission, 1997).

Natural landscaping applies to an array of landscaping techniques that incorporate native vegetation, particularly prairie, wetland, and woodland plants. Natural landscaping also includes natural drainage techniques, such as swales and vegetated filter strips, instead of storm sewers and artificial drainage channels.

Benefits

The benefits of natural landscaping are the most broad-ranging of any of the retrofitting techniques. In addition to water quality benefits, they include flood reduction, habitat enhancement, improved air quality (climatological benefits) aesthetic enhancement, and cost-savings.

Water quality benefits are derived in two ways. First, unlike conventional landscapes of turf grass and ornamental plants, native plants do not usually require chemical additives after their initial establishment. Fewer applications mean greatly reduced runoff of fertilizers, pesticides, and herbicides. Second, natural landscapes, particularly with the deep root zones of many native plants, can effectively soak up, filter, and transform contaminated stormwater runoff from roadways and parking lots, greatly reducing the pollutant loads discharged to the "receiving stream".

Flood reduction occurs due to the greater infiltration capacity provided by deep-rooted native plants. In contrast to the four-to-six-inch root zones of turf grass, the dense root systems of native prairie plants commonly extend several feet into the soil, creating passageways for the rapid infiltration of precipitation and runoff. The dense root systems also enhance evapotranspiration.

Habitat enhancement is provided by the diversity of plants found in a natural landscape, in contrast to the conventional near-monotypic stand of turf grass. Native wildflowers host numerous birds and insects whereas turf will not. Natural landscapes are particularly valuable adjacent to lakes and streams where they provide habitat for aquatic insects and amphibians that spend time both in the water and in terrestrial environments.

Improved air quality results, in part, from reduced usage of lawn maintenance equipment that discharges hydrocarbons and nitrogen oxides into the environment. Native plants also enhance air quality by filtering out particulates and converting carbon dioxide to oxygen. In a related manner, natural landscapes (particularly trees) provide climatological benefits via shading and wind breaks, thereby moderating temperatures and enhancing human comfort.

Natural landscaping also can provide *aesthetic enhancement*. Natural landscapes provide a great variety of textures, colors, and shapes that vary seasonally. They also attract a variety of wildlife, particularly birds and butterflies, enhancing their visual appeal.

The *cost-savings* in maintenance costs of natural landscapes can be dramatic. Natural landscapes need little of no fertilizer or pesticide, as already noted. They do not require regular irrigation, as does turf. They also need little or no mowing. The preferred long-term maintenance approach for many naturally landscaped sites is prescribed burning, performed every one-to-three years, much as it was done by Native Americans.

Local Examples

Natural landscaping has been retrofitted onto numerous sites throughout northeastern Illinois. Most of the retrofitting has occurred on residential lots. In terms of community impact, some of the most striking retrofits have been on large office campuses and public properties.

Residential landscape conversions commonly involve the replacement of turf grass or annual flowers with perennial wildflowers and prairie grasses. Most conversions occur gradually as residents discover and appreciate the advantages of natural landscaping. In some cases, virtually the entire lawn is converted, although in many cases significant buffers of conventional landscaping are retained to minimize potential conflicts with neighbors. As public education and acceptance increase many communities that formerly prohibited tall grasses and ungroomed landscapes, are now growing more flexible toward natural landscapes.

Commercial and office campus sites provide some of the most impressive examples of natural landscape conversions owing to their high visibility and large expanses of land. Notable examples include the AT&T corporate campuses in suburban Lisle and Naperville and the Prairie Lakes commercial redevelopment in Homewood. Natural landscape conversions on these sites have been motivated by a combination of factors, including corporate image, and the influence of employees.

Public properties, notably schools, parks, government centers, and roadways, are increasingly popular targets for landscape retrofitting. Schools provide logical retrofit opportunities considering their typically large expanses of high-maintenance turf and the potential educational opportunities. Wheaton Warrenville South High School, for example, retrofitted 2.5 acres of turf into dry and wet prairie vegetation. Students have been involved in planning, planting, and management of the restored areas.

Restoring Stream and Rivers

The streams and rivers of northeastern Illinois reflect a history of abuse and neglect. Over 40% of the stream miles have been channelized or severely modified to provide agricultural drainage or accommodate urban development. Uncontrolled development of upstream watersheds has led to severe flooding, streambank erosion, and water quality degradation. Hence, there is a great need and opportunity for retrofitting. In the context of this paper, retrofitting is used to describe stabilization or limited rehabilitation of the physical characteristics of the channel and its riparian zone. Retrofitting includes stabilization of eroding banks, enhancement of instream habitat, and restoration of the near-stream riparian zone (Dreher 1998).

Benefits

Potential benefits include bank stabilization, improved water quality, improved habitat, and enhanced aesthetics.

Bank stabilization can be achieved by a number of techniques. The preferred approach would incorporate the use of soil bioengineering techniques that are largely based on natural materials and vegetation. Effective bank stabilization reduces the loss of riparian land, protects streamside infrastructure (such as bridges and buildings), and reduces sediment load.

Water quality improvement can be accomplished by a number of retrofit techniques. One way to improve water quality is to restore the natural pollutant filtering capability of the riparian zone and floodplain. This is most readily accomplished by re-planting streambanks and riparian buffers with native vegetation, particularly indigenous wetland, prairie, and woodland plants that were common prior to settlement. Another way to improve water quality is to stabilize stream temperatures. Often, degraded streams suffer from over-heated conditions during the summer due to a loss of shading in combination with overly-wide, shallow channels. Establishing native vegetation, particularly along sensitive headwater streams, can result in substantial improvements.

Stream habitat is improved by restoring critical elements such as meanders, pools, riffles, and natural substrate to a degraded channel. Some habitat improvements can be readily accomplished as part of other stream rehabilitation projects. For example, the addition of rock substrate at appropriate locations can accomplish both riffle enhancement and stream bed stabilization. However, restoration of meanders to a straightened stream channel typically would be performed as an independent restoration project.

Aesthetic enhancement is accomplished in most restoration projects, whether intended or not. Replanting of native vegetation to stabilize an eroded streambank, for example, also results in a visual improvement. Intentional enhancement of a degraded stream may be in the best interest of some land developers, particularly of residential properties, to improve the marketability of a project. For example, re-meandering and replanting a channelized stream can convert an ugly ditch into an attractive stream in the eyes of home buyers.

Local Examples

The Northeastern Illinois region has been the fortunate recipient of funding to implement several stream restoration demonstration projects. These projects, funded principally through Section 319 of the Clean Water Act, have provided highly visible models for others to emulate.

Two projects in which the Northeastern Illinois Planning Commission has been involved are restorations of the Skokie River and Flint Creek, located in suburban areas north and northwest of Chicago, respectively (Price, 1997). Both projects successfully demonstrated the use of “soil bioengineering” techniques for streambank stabilization and both restored significant areas of riparian buffer. The projects also attempted to restore instream aquatic habitat, although on a limited basis.

Several *parks and golf courses* have implemented stream restorations to beautify their grounds and to reduce the loss of recreational lands to excessive streambank erosion. Such restoration projects have utilized public education to overcome the historical bias that favors manicured landscapes over ungroomed “natural areas.”

Several large *residential developers* have implemented, or initiated planning for, significant stream restoration projects. These have been done with the intention of enhancing the visual appeal of the developments and/or accommodating development on sites constrained by floodplain locations. Whatever the motivation, aquatic habitat, water quality, and hydrologic functions stand to benefit substantially. A notable example is the Fox Mill development in west suburban Kane County. This project resulted in the re-meandering of the ditched headwaters of Mill Creek and the conversion of a large riparian buffer to native wetland and prairie.

Citizen organizations have been active in stream restoration. These include loosely organized volunteer groups as well as land trusts that actually own and manage land. Restoration activities have ranged from streambank stabilization projects supported by volunteers to more-extensive restorations of riparian buffers and wetlands. Notable examples include the restoration of a 1000-foot buffer along Flint Creek by the Citizens for Conservation and the rebuilding of 200 feet of river edge and restoration of a riparian buffer along the Middle Fork of the North Branch Chicago River by the Lake Forest Open Lands Association (Price, 1997).

Retrofitting Stormwater Detention Basins

Northeastern Illinois communities have required stormwater detention for new development since 1970. Currently, the vast majority of municipalities and counties have detention ordinances. While local ordinances are some of the most restrictive in the nation with respect to flood prevention, most have not incorporated water quality designs until the recent past. For example, many older basins are simple dry bottom designs, often with paved low-flow channels, that provide little pollutant removal benefit. Thus, there are substantial opportunities to retrofit older basins to enhance their effectiveness. Retrofitting projects can range from simple repairs or alterations to major rehabilitation, depending on the project objectives and the existing conditions of the basin.

Benefits

Detention basin retrofitting can be targeted to a range of objectives. These include improved pollutant removal, improved flow control, reduced maintenance, and enhanced aesthetics.

Improved pollutant removal can be achieved in most older dry-bottom basins. One retrofitting technique is to revegetate basin bottoms with wetland plants in place of turf. If paved low-flow channels exist, they can be replaced with vegetated swales. Pollutant removal also can be enhanced by excavating settling basins at the inlets and/or outlet of the existing basin. Settling basins can greatly enhance the removal of suspended solids and attached pollutants. Outlet structures also can be modified to increase detention times for small-to-moderate-sized storms, thereby enhancing pollutant settling. Finally, pollutant removal can be enhanced in basins where inlets and outlets are located in close proximity, causing short-circuiting. This is accomplished by lengthening flow paths through the construction of low berms.

Improved flow control can be readily achieved in some basins by modifying the outlet structure. This is particularly beneficial in older basins that were designed to control only the 100-year discharge. The outlets of such basins can be retrofit with restrictor plates or berms, or replaced with completely new structures, to provide control of smaller storm flows, such as the 2-year event. Such control is important in stabilizing downstream flows to reduce the potential for streambank erosion. However, it should be recognized that increasing the control of smaller storms will result in less storage availability for larger flood events.

Reduced maintenance is an objective in many older basins. One way to reduce maintenance is to replace turf grass on basin bottoms and side slopes with low-maintenance native vegetation. Depending on wetness conditions, either wetland plants or prairie grasses and wildflowers can be used. Native vegetation requires only occasional mowing or prescribed burning. Maintenance needs can be reduced in some basins by excavating settling basins at basin inlets. Properly sized basins can concentrate the settling of most particulate matter at the inlets, thereby facilitating long-term sediment removal from the basin.

Enhanced aesthetics is a concern in many older basins. Problems range from eroding shorelines to excessive populations of Canada geese. Shoreline erosion in wet-bottom basins can be controlled with the introduction of buffers of water-tolerant native vegetation into shoreline zones. Where erosion is severe, installation of soil bioengineering measures, as previously described for stream restoration, can be effective. Introduction of shoreline buffers of taller native plants also can be an effective control for Canada geese. Indications are that geese are not comfortable moving through tall vegetation and are, therefore, more likely to seek conventionally landscaped basins. They also prefer short turf grass as a food source.

Local Examples

In contrast to natural landscape conversions and stream restorations, there has not been a widespread retrofitting of detention basins in northeastern Illinois. Perhaps the most likely explanation is that detention basin owners generally are unaware of the performance deficiencies of older basins, particularly their inability to effectively remove stormwater pollutants. Without regulatory incentives for such retrofitting, little has occurred. Detention basins owners are more responsive to maintenance and aesthetic concerns. Consequently, older detention basins are being retrofit with native vegetation and shoreline stabilization measures.

The most notable detention retrofitting project in the region is a demonstration project funded in part by the U.S. EPA through Section 319 of the Clean Water Act. This project involved an older dry-bottom basin in the Village of Flossmoor, approximately 30 miles south of Chicago (Price and Dreher, 1995). The basin had a failed outlet structure, due to sediment clogging, and a paved low-flow channel between its principal inlet and the outlet. Retrofitting involved the excavation of stilling basins at the two basin inlets, excavation of a permanent pool at the outlet, installation of a new multi-orifice outlet structure, and revegetation of the basin bottom and side slopes with native wetland and prairie vegetation. The retrofit basin provides substantially improved pollutant removal and improved hydraulic control of small storms, and requires substantially less maintenance than the former basin. Local residents have indicated their satisfaction with the aesthetics of the retrofit basin, as well.

Converting, or "Daylighting," Storm Sewers

The term "daylighting" refers to the elimination of a storm sewer or culvert and its replacement with open channel flow. On the principle that open drainage systems provide certain natural and aesthetic functions not provided by artificial, underground systems.

Benefits

There are several potential benefits of converting closed pipes to open channels. These include improved water quality and hydrologic functions as well as aesthetic benefits. These benefits are optimized when the open channel is designed as a natural, unlined swale or stream.

Several *water quality benefits* are likely to result from storm sewer daylighting. By running stormwater through an open, vegetated channel, runoff pollutants can be filtered and transformed by a combination of physical and biological processes. These processes, similar to those occurring in natural swale and stream systems, are constrained in closed pipes by inadequate light and the absence of natural substrates.

Improved *hydrologic functions* also are likely to result from sewer daylighting. For example, flow in an open swale will have some opportunity for infiltration, thereby enhancing natural recharge and baseflow. Natural open channels also can better dissipate flow velocities, potentially reducing downstream flooding and channel erosion.

Aesthetic benefits are most readily appreciated at the point where a storm sewer or culvert discharges to a receiving stream or lake. Eliminating storm sewer bulkheads, in particular, is likely to enhance the visual appeal of a bank or shoreline, and enhance recreation in the waterbody (Dreher and Price, 1997).

Local Examples

There are few reported examples of storm sewer daylighting in northeastern Illinois, although there is increasing interest in the concept among watershed managers. One documented project is the conversion of several hundred feet of large diameter storm sewer serving downtown Barrington, northwest of Chicago. As part of a redevelopment project, the Village removed the storm sewer and replaced it with a meandering wetland swale. The objectives of the project were to enhance the quality of the discharge into nearby Flint Creek and to improve the appearance of the property from an adjacent park and a planned trail (Price, 1997).

Several area watershed groups are currently discussing opportunities for daylighting. In particular, the Friends of the Chicago River, as part of a comprehensive watershed management project, have identified storm sewer daylighting as a remedial best management practice (BMP). It is notable that in some areas of the North Branch Chicago River watershed, nearly all of the historical surface drainage system has been replaced by storm sewers. In this context, storm sewer retrofitting will not only benefit the river but also may educate local residents to the advantages of a natural drainage system looks like.

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Impacts of On-site Sewage Systems and Illicit Discharges on the Rouge River

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The focus of the Rouge River National Wet Weather Demonstration Project (Rouge Project) is to clean up the Rouge River in southeast Michigan. The Rouge River watershed includes portions of the City of Detroit and 47 communities west and northwest of Detroit. Water quality sampling and models show that eliminating combined sewer overflows (CSOs) alone will not ensure that water quality standards are met or that the river can be used for all purposes the public desires. The information presented in this paper shows that non-stormwater sources, such as on-site sewage systems and illicit discharges, are major contributors to the contamination of the river.

On-site Sewage Disposal Systems

On-site sewage disposal systems (OSDS) exist in urban areas of the Rouge River Watershed and are contributing to surface and groundwater pollution. In Wayne, Oakland, and Washtenaw Counties, OSDS requirements exist only for the installation of such systems; operation and maintenance are the responsibility of the owners. Rouge River OSDS failure rates documented in surveys conducted in 1994, 1995, and 1997, varied between 17 and 55%. The 1995 and 1997 studies evaluated 528 residential OSDS for failures, which were identified by the following:

- observation of sewage discharging from the area of the OSDS
- observation of liquid on the ground surface of the disposal field
- identification of a pipe draining sewage from the disposal field area
- heavy vegetation on or near the OSDS
- detection of dye in surface water downstream from the septic tank after dye was placed in the septic tank.

Some surface waters in sewered communities have been found to be unsafe for human contact due to high levels of *E. coli* bacteria. Sources of *E. coli* here include CSOs, sanitary sewer overflows and leaks, illicit connections, wildlife excrement, and failing OSDS. Illicit dumping of septic wastes from recreational vehicles may also contribute to occasionally high *E. coli* counts. Some surface waters that drain areas which are not served by sanitary sewers have also been found to be unsafe for human contact due to high *E. coli* bacteria counts. These unsewered areas are served by OSDS. Other potential sources of *E. coli* bacteria here are illicit discharges through pipes that drain to surface water, wildlife excrement, and agricultural operations.

In order to perform the OSDS surveys, it was necessary to identify the locations of systems installed in the study areas. While local health departments issue permits for OSDS installations, three of the four health departments in the Rouge River Watershed have not entered permit information into computerized databases. Local communities did not have records of OSDS. Each of the surveys required the development of a database of OSDS permit information to help locate systems in the field. Census data from 1990, which included information about the numbers of OSDS by city block, were used to identify areas served by OSDS. Information available from water utility billings from each community was also included in the OSDS databases, along with the results from the field surveys. Results from compiling the databases were surprising to local governments. These included the following:

- The 1990 census data showed that there are more than 1,700 OSDS within Detroit city limits. City officials were surprised at these figures, since on-site sewage disposal systems are illegal in Detroit.
- Further checking indicated that there are areas in the City not served by sewers. Although a City policy ex-

ists requiring payment for sewer connections, no follow-up has occurred to verify that connections have taken place.

- Utility billings were screened for three communities in the study area to identify households that were paying for water but not for sewer service. Homeowners who were billed for sewer service (e.g., were connected to sewers) were not surveyed. Results through September 1997, revealed the following:

Community	Total Number of Homes Contacted	Homes with City Sewer Connection	Total Homes with OSDS	Homes with OSDS that are Failing
A	152	18	134	28
B	239	22	217	45
C	53	15	38	6

- Of the 444 homes contacted, 55 reported that they are connected to the city sewer but are not paying sewer charges.

- Of the 389 homes surveyed with OSDS, 79 had failing systems (20% failure rate).

- None of the communities were aware that homes were connected to sewer systems but not being billed for service. These communities are losing revenue by not recovering costs of operation and maintenance of the sewer system from these customers.

Wayne County Study

The Rouge Project Office funded a grant to Wayne County to conduct visual surveys of OSDS for homes located along a Rouge River tributary that drains into an area being considered for canoeing. Because of high *E. coli* bacteria counts, canoeing on the river has been discouraged. Through October 31, 1997, the County had conducted surveys for 427 homes to identify signs of OSDS problems. Of these, 90 systems have been described as failing or potentially failing—a failure rate of 21%. Typical descriptions from the field notes were as follows:

- Sewage backup in the home.

- Gray water discharging to the ground surface.

- Standing water on top of the gravel seepage field.

- Mushy area, associated with the back end of an apparent seepage field.

- Illicit connection and undersized septic tank (100 gallons) drained by a trench type (long single perforated pipe) seepage field.

- Black sludge residue and toilet paper debris around surface of the septic tank covering.

- Growth of cattails, wet marsh on the face of a downward sloping hill.

Oakland County Study

Another study, which took place in the Oakland County portion of the Rouge River Watershed, included dye testing septic tanks and stream sampling for fecal coliform, *E. coli* bacteria, and benthic macroinvertebrates. Study results are as follows:

- Of 49 surface water sampling sites, 43% had a daily geometric mean for *E. coli* bacteria of 1,000 or more per 100 milliliter of sample.

- The macroinvertebrate study was done to determine the water quality of streams in the survey area. A scale was developed to rate macroinvertebrate and water quality. The results in the study area ranged from 7, which indicates poor water quality, to 20, which is considered good water quality.

- Dye testing conducted in 1994 showed that 53% of the homes tested had discharges to the river.

- An optical brightener test to detect laundry waste was conducted at the river sites where dye was collected. These were all negative.

- Dye testing conducted in 1995 showed a 39% failure rate for OSDS in the communities surveyed.

Future Direction

The future direction of this effort is to establish, in cooperation with local health departments, an on-site sewage management program in each community. Communities are also encouraged to address on-site sewage systems in applications for general stormwater permits issued by the State of Michigan under the National Pollutant Discharge Elimination System (NPDES) Program. Septage disposal problems are being addressed with septage haulers and disposal facilities.

Costs

Grant expenditures for the Wayne County and Oakland County surveys were $105,000 and $61,000, respectively. This includes amounts spent by agencies to administer the grants, conduct the investigations, and complete necessary reports and other documentation. Additional costs were realized by communities required to extend sewers to problem areas and homeowners who were required to correct failing OSDS or connect to available sewers.

Illicit Connections

From 1987 through 1996, Wayne County investigated approximately 3,340 businesses and industries for illicit connections to the storm sewer system. Approximately 9% of the facilities inspected were found to have illicit connections. The elimination of these improper discharges has diverted raw sewage and other pollutants from the river to the wastewater treatment plant. Findings of the investigation are as follows:

- An average of 2.6 improper connections were found at businesses that had illicit connections.

- The majority of illicit connections in non-residential facilities were drains connected to storm sewers. These included floor drains, trench drains, interior catch basins, oil separators, machine process water drains, and sump pumps. The categories of illicit connections found were floor drains (46%), sinks (20%), washing machines (15%), toilets (11%), and a variety of others (8%).

- A method to prioritize the investigation was developed based on the Standard Industrial Classification (SIC) of businesses. The prioritization method was successful for locating illicit connections. It was not helpful in locating illicit discharges of *E. coli*.

- The use of aerial, infrared, and thermal photography to locate discharges that have a higher temperature than that of the stream, or locations where algae might be concentrated, is in the experimental phase. The aerial infrared experiment also examines soil temperatures, land surface moisture, and vegetative growth. Assumptions are that (1) a failing OSDS will have increased moisture in the surface soil, (2) the area will be warmer, and (3) vegetation will grow faster than the surrounding area. These differences should be visible in the digital data. Analysis of data collected has been hampered by a lack of resources to conduct field work needed to develop computer references.

- To date, there have been no definite correlations among field tests for ammonia, anionic surfactants (detergents), and *E. coli*.

- Field crews and members of the public have identified a significant number of improper discharges to the river through visual observations.

- Stable isotopes of oxygen and hydrogen have been used to determine the presence of sanitary sewer water in discharges.

- Visual observations and liquid flow testing indicate that 160 manholes and outfalls have suspicious discharges.

- Based on these findings, the estimated number of potential illicit violations in the entire Rouge River Watershed is 5,260.

It is estimated that 51 million gallons of liquid will be discharged from illicit connections within the Rouge River Watershed. Field work performed during dry weather (72 hours without precipitation) identified 160 manholes and outfalls that had ammonia readings of 1.0 or greater, or had visible conditions that were cause for further investigation. All of these manholes were investigated for ammonia, anionic surfactants, and *E. coli*. The bacteria results showed that 16 locations had *E. coli* bacteria counts greater than 5,000 per 100 ml. These locations will have a detailed investigation to locate the source. Many of the areas with suspicious discharges are residential areas. Municipalities will be requested to participate in finding improper connections.

Work performed in 1997-98 will focus on locating sources of *E. coli* that are impacting the Rouge River from Nankin Dam to Merriman Road, a distance of approximately 1.5 miles. This is a prime area for recreational activity, which would be significantly increased if the river was safer for human contact. The work will begin at the 16 manholes/outfalls with high *E. coli* bacteria counts mentioned above. Manholes located upstream of the sampling sites will first be tested. Each highly suspect source will be dye tested to confirm whether or not it is contributing to high *E. coli* counts. Sampling of Tonquish Creek and its tributaries that drain into the proposed canoeing site will be conducted during dry weather to determine if the same process will be needed in this area.

An example of going upstream from a trouble spot to locate the source of pollution is the investigation of a storm sewer relief drain. An 11-foot storm sewer had been under suspicion for several years. In 1997, samples were collected from manholes located upstream from the discharge point. Samples collected in June from one of the laterals connected to the sewer had *E. coli* counts of 8,160 and 9,600 per 100 ml. Additional samples were taken five days later. Levels of *E. coli* from samples taken progressively upstream in the storm sewer where the 9,600 per 100 ml count was found were 12,560; 24,000; 160,000; and 9,600 per 100 ml. A lateral of this sewer had a result of 4,800 *E. coli* per 100 ml. The manhole with the 160,000 per 100 ml count was found to be the “hot spot.”

The results of this sampling activity were shared with city officials who decided to have the sewer televised. However, the tapes did not show any suspicious connections. Plans were then made to begin dye testing at homes located next to the storm sewer. Before beginning the process of dye testing, another sample was taken at the trouble spot to have current information. The results of that sample indicated less than 8 *E. coli* bacteria per 100 ml. Following discussion with the city, it was agreed that dye testing would be postponed. It was also agreed that residents would be informed of the sampling activities that had taken place on their street. At this point, it was felt that the high *E. coli* count from the initial sample may have been due to an incident of someone dumping wastes directly into the sewer. A letter was sent to residents asking them to let the city or county know if they had knowledge of any practices that could have resulted in the high *E. coli* counts. As a result of these sampling activities, this investigation, and community interest, sampling continues on a monthly basis on this street.

Future areas to be checked will be identified based on citizen complaints, a review of manhole and outfall sampling to determine contributing conveyances, and instream/insewer sampling to localize the area. Using Rouge Project GIS, maps have been prepared for tracking the sampling of manholes and outfalls. These maps and the sampling data help municipalities identify and prioritize areas that need to be further investigated.

Future Direction

The future direction of illicit connections/discharges is to have each community in the Rouge River Watershed commit to actively exploring illicit connections/discharges. Grants and assistance from county agencies are available to communities and agencies. As part of an application for a General Stormwater Permit from the State of Michigan under the NPDES program, a community is required to develop an Illicit Discharge Elimination Plan. The Rouge Project assists communities in preparing these applications. Elements of the Illicit Discharge Elimination Plan recommended to be included are (1) a legal basis for the program, (2) how problem areas will be identified, (3) how the sources will be pinpointed, and (4) how to achieve correction, evaluation, and reporting.

Costs

The budget for the Illicit Detection Investigations Program in 1996-97 was $735,000. The budget for the 1997-98 program is $599,000. Besides field work, this budget includes trials of different methods of investigation, testing, and subcontracting for special studies. There is also a significant cost for grant administration. Not included are costs likely to be incurred by businesses to correct illicit connections or the cost to communities of televising sewers to locate illicit connections. The 1997-98 program provides nine full-time-equivalent employees. Of these, six perform investigations and water sampling.

Stormwater Management in an Environmentally-Sensitive Urban Bushland in Sydney, Australia

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Introduction

This paper outlines and discusses the challenges faced, and the techniques employed, by the Upper Parramatta River Catchment Trust in developing and executing an integrated stormwater management strategy in an environmentally sensitive bushland reserve in the middle of the Sydney metropolitan area, in New South Wales, Australia.

The key element of the strategy was a 30-metre high concrete wall and associated structures, which form a large flood detention basin in the bushland reserve. Completed in mid 1996, the flood basin protects over 300 properties in several residential and commercial areas from major floods.

As part of the overall project, complementary measures such as bushland regeneration, creek bank stabilisation, water quality monitoring and sediment and litter traps were implemented in the reserve to overcome serious existing degradation of the bushland and protect it from further degradation.

The adopted strategy was considered to be the best possible compromise between the need to protect the bushland environment and the need to protect homes, offices and factories from flooding. This paper briefly outlines the history of the project and some of its more noteworthy features.

Background

The Upper Parramatta River watershed or catchment forms the headwaters of Sydney Harbour in the city of Sydney, in the State of New South Wales, Australia. As shown in Figure 1, the catchment is located in the centre of the Sydney metropolitan area, between 20 and 30 kilometres west of the Sydney central business district. The outlet of the upper catchment is at a weir separating the freshwater and estuarine sections of the river. This is located just downstream of the Parramatta central business district, the main commercial centre for western Sydney.

The area of the catchment is 110 square kilometres and has a population of 230,000. Most of the catchment's 70,000 properties are single detached residences, although there are extensive commercial and industrial areas and an increasing number of multiple occupancy dwellings. Much of the catchment is urbanised, although there are significant areas of remnant vegetation in bushland reserves and urban forests, most located along the creeks.

Figure 2 shows that the two main tributaries of the Parramatta River are Toongabbie Creek which drains the west and south of the catchment and Darling Mills Creek which drains the northeast.

The upper Parramatta River catchment includes portions of the areas of four local authorities (called local councils in Australia). Baulkham Hills, Blacktown and Holroyd cover the upslope areas in the catchment's north, west and south respectively, whilst Parramatta covers the catchment floor.

Although the catchment has experienced flooding since the earliest days of European settlement from 1788, the problem was compounded by rapid urban development of the catchment in the 1960s and 1970s. At that time the hydrologic impacts of urbanisation were not appreciated and there was a lack of cooperation among the local councils. The growing flood threat only became apparent during a series of storms in the late 1980s, which inundated hundreds of properties many times. Detailed flood studies showed that, in storms only marginally larger than those experienced, substantial areas including much of the Parramatta central business district would be flooded.

The historic Lennox Bridge over the Parramatta River at Parramatta increases the risk of serious flooding in the Parramatta central business district. Constructed in 1837, this sandstone arch bridge is the third oldest bridge in Australia. Unfortunately, its arched waterway opening means that, as the river level rises, less and less additional waterway is available to pass flows.

Hydraulic studies showed that once the river level reaches the top of the arch opening, as almost occurred in the 1986 and 1988 floods, the river would break its banks and quickly flood substantial areas of the central business district. The flood risk, and the consequential development

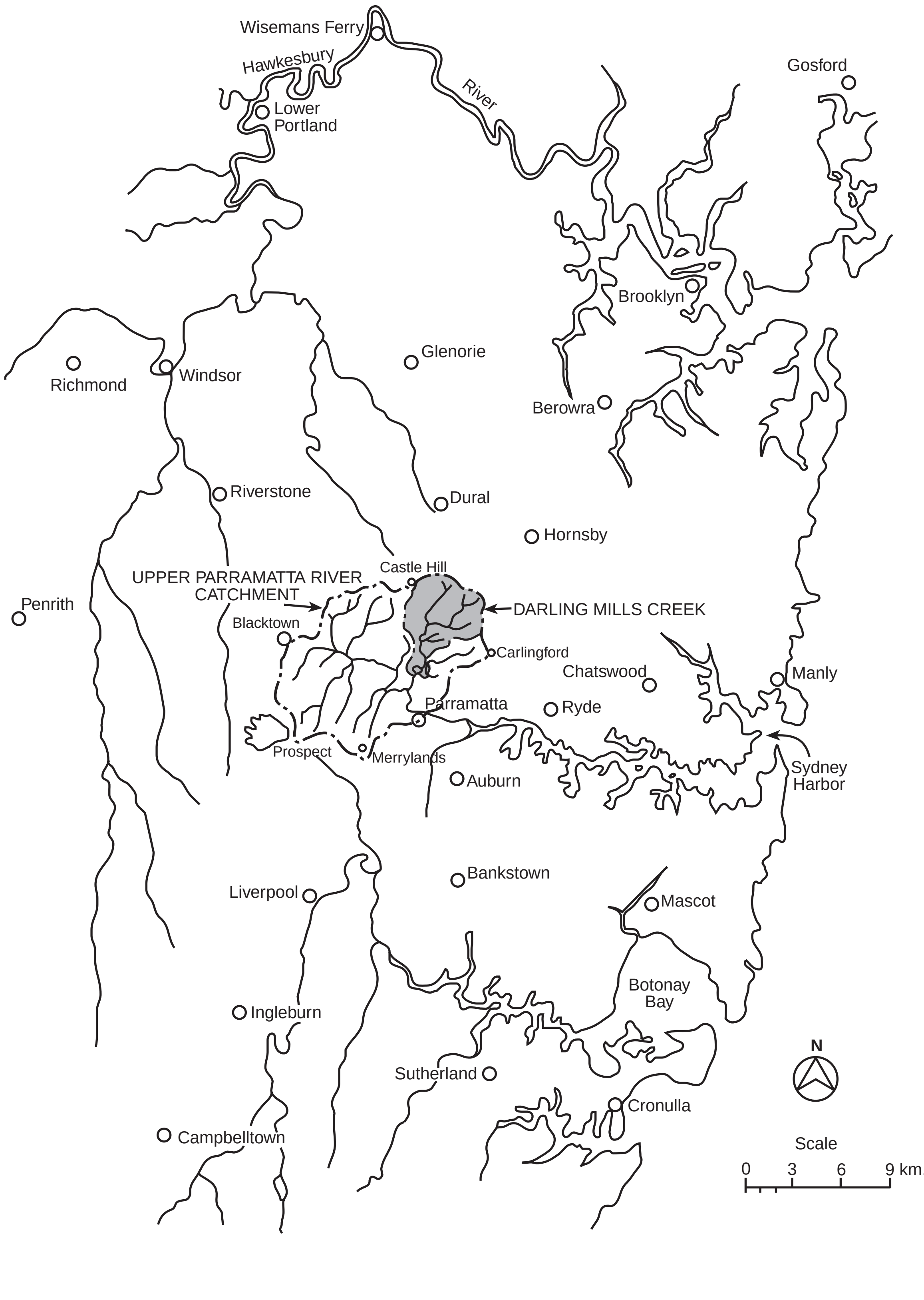

Figure 1. Location of catchment in relation to Sydney

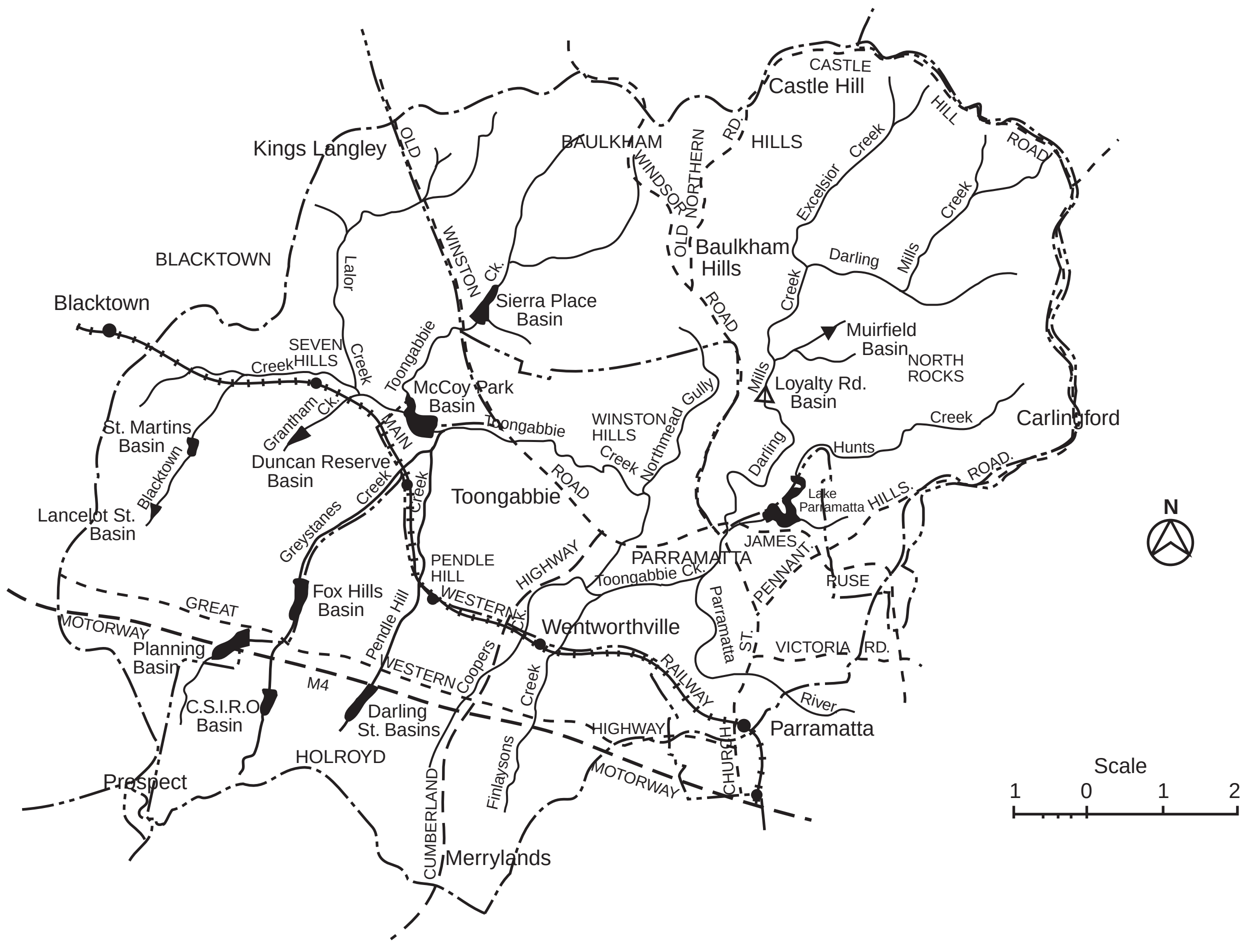

Figure 2. Location of existing flood detention basins in catchment

restrictions imposed by the Parramatta Council, caused the affected parts of the central business district to become rundown.

A proposal in 1991 to reduce peak flood levels by demolishing Lennox Bridge was narrowly voted out by Parramatta City Council. Soon after, the state government put a ‘permanent conservation order’ on the bridge, effectively ruling out that option.

Attention then turned to alternative solutions, particularly in the Darling Mills Creek sub-catchment. Although this sub-catchment occupies only one-third of the upper catchment, it contributes half the storm flows because of its higher rainfalls and steeper slopes. Moreover, as shown in Figure 2 there were seven large flood detention basins and several smaller basins in the Toongabbie Creek sub-catchment; there were none along Darling Mills Creek.

For most of its length, Darling Mills Creek flows through a heavily vegetated and steep-side sandstone valley up to 100 metres deep contained within a publicly owned bushland reserve, Excelsior Reserve. Urban development surrounds Excelsior Reserve on all sides. Despite this, the dense vegetation and the deep valley, together with massive sandstone cliffs, create a sense of wilderness which many local residents make use of for bushwalking and quiet relaxation.

The extensive urban development surrounding Excelsior Reserve has also caused the creek’s water quality to deteriorate and the bushland either side of Darling Mills Creek to become degraded. The reserve was infested with weeds, there was severe creek bank erosion in places, and considerable litter and nutrients were swept into the reserve by stormwater. Despite voluntary bushland regeneration work by local residents, Baulkham Hills Shire Council has been unable to allocate the funds needed to overcome the degradation.

Investigations

Because the issues involved two local council areas Baulkham Hills and Parramatta, investigations into a possible solution were sponsored and managed by the Upper Parramatta River Catchment Trust, the catchment management authority for this area.

The trust had been established in 1989 following representations by local authorities and the public in the wake of several major floods. It is a state agency funded by an annual levy on all catchment properties. The trust's charter is to coordinate flood mitigation, water quality and related catchment management activities in accordance with the NSW Government's integrated catchment management policy. It has a part-time board of twelve directors (nominated by the four local councils and relevant state government agencies) and a permanent staff of seven.

The future of the trust is currently being considered in the context of a planned catchment management body for the entire Sydney Harbour catchment.

Initial studies by the trust showed that a large flood detention basin in the bushland reserve on Darling Mills Creek was the only viable way to protect from floods over 300 properties in the Parramatta central business district and four other flood-liable areas along Darling Mills Creek and the Parramatta River.

This immediately posed three significant challenges because it meant:

- building a large structure in an environmentally sensitive bushland;
- storing floodwater temporarily in a heavily vegetated reserve (until then detention basins had only been built on grassed playing fields); and
- creating a large detention basin in the upstream local council area (Baulkham Hills) to protect properties in the downstream local council area (Parramatta) from flooding.

Community Consultation — Support and Opposition

From the outset, a community group formed to protect the bushland reserve signalled its strong opposition to the proposal for a large flood basin in the reserve. Despite its strident opposition, the group participated in the workshops and meetings held whilst the proposal was being formulated and its impacts assessed. Other groups from flood-liable areas further downstream were vocal in expressing support for the flood basin.

A project steering committee was formed with representatives of the trust, both councils, government agencies and groups supporting and opposed to the flood basin. The committee met regularly during the course of the investigations. In addition, two community workshops were conducted to obtain community feedback at critical stages. Finally, a two-day Value Management Workshop to assess the most favourable alternative was conducted by an independent facilitator. Progress reports were published in the trust's quarterly newsletter delivered to all catchment households.

Investigations and Design

Although not legally required, the trust decided to prepare an environmental impact statement (EIS) to support a formal application to Baulkham Hills Shire Council to implement the stormwater strategy, including the large detention basin. This ultimately involved some 40 separate environmental, social, economic and technical studies over two years at a total cost approaching $500,000 (Australian dollars). The issues addressed ranged from Aboriginal archaeology, acoustics and air quality, to water quality, weed control and zoology.

Of these issues, the most controversial was the likely impact of the basin on vegetation in the impoundment area. It was claimed that the raised flood levels inside the basin would spread weeds to higher elevations in the bushland reserve, whilst raised soil moisture levels would eventually kill off mature trees. This issue proved difficult to resolve because of the apparent absence of other detention basins in bushland areas. In general, studies of other issues found that impacts of the basin would be minor and could be effectively mitigated.

A key part of any EIS is the assessment of all feasible alternatives to the favoured option. Opponents of the large basin sought to frustrate the EIS by repeatedly proposing alternatives that, it was claimed, would avoid the need for the basin. Each had to be examined carefully. In all, 20 alternatives or groups of alternatives were assessed, including different large basins, groups of small basins, bridge modifications, a flood tunnel by passing Parramatta, acquisition of flood-liable properties and/or compensation.

The first stage of the evaluation confirmed that only a large basin in Excelsior Reserve would protect all at-risk communities at an affordable cost. The second stage evaluation showed that the basin site near Loyalty Road, North Rocks, was clearly superior on environmental, social and financial criteria. This conclusion was confirmed at the Value Management Workshop run by an independent facilitator.

Different types of basin walls (dams) were also examined. On technical, environmental and financial criteria, it was found that a mass concrete wall constructed with roller-compacted concrete (RCC) would be best. The concept design was refined and detailed plans prepared. The design team included Ernest Schrader of the US, the world's foremost expert in the roller-compacted concrete technique. Mr. Schrader visited for a week during the design work, and again during the construction.

The basin wall was to be 23 metres (at the spillway) to 30 metres (at the abutments) high, and 110 metres long at its maximum height. It would comprise 23,000 cubic metres of RCC, with pre-cast concrete panels on its external faces. Its upstream face would be vertical. Its downstream face would consist of a series of steps and have an overall slope of 0.8 to 1. A central spillway, with walls either side, was designed and model tested to safely pass even the largest possible flood. A 2.5 by 2.7-metre culvert allows passage through the wall and contains a 1-metre square low-flow channel.

Some key issues and concerns identified during preparation of the EIS are listed in Table 1, together with how each was addressed.

The basin would have a maximum flood storage capacity of 1.5 million cubic metres. Detailed hydrologic and hydraulic studies conducted by the trust showed that the flood basin would reduce the peak flow in the critical 1 in 100 (1%) annual exceedance probability (AEP) storm by 75%, reducing the number of flood-liable properties further downstream from 313 to 75. However, all detained floodwater would drain away within 3 to 6 hours of the rainfall easing; and flows in the creek would be unaffected for more than 99% of the time.

Development Consent

In early September 1994 the trust submitted its development application to Baulkham Hills Shire Council. This was supported by an EIS comprising a 350-page main re-

Table 1. Darling Mills Creek Stormwater Management Strategy - Addressing Key Concerns

Issue or Concern	How Addressed
Most flood mitigation benefits in another local council area (Parramatta).	Flood basin 'packaged' with various environmental measures to address serious degradation of the Excelsior Reserve bushland and the creek.
Fear that temporary flooding of bushland would kill or degrade vegetation.	Flood studies showed that all stored water will drain away within 3 to 6 hours of heavy rainfall easing. Baseline surveys made of vegetation and creek channel against which future changes can be assessed. Similar detention basin in Adelaide Hills of South Australia found to have caused no significant harm to upstream bushland after 30 years.
Visual intrusion of large man-made structure into natural setting.	Basin wall sited within a creek meander so that the wall is only visible within 50 metres upstream and downstream. Texture, width and colour of external panels designed to blend in with shadows from nearby tall trees.
Loss of bushland area due to structure.	Basin wall constructed using roller-compacted concrete to minimize its 'footprint' — only 2 hectares in 300-hectare reserve.
Raised water levels in basin will spread weeds to higher levels in valley.	All weeds removed from the basin area and up slope to prevent the spread of weeds. Ongoing bush maintenance to control weed regrowth.
Basin wall will block use of track along bank of creek by hikers and animals.	Culvert through the bottom of the wall allows normal creek flows to flow through, and enables hikers and animals to pass from one side of the wall to the other.
High-velocity water discharging through culvert in basin wall (up to 15 metres per second) will scour downstream creek banks.	Dissipater structure and stilling basin designed and model tested to control the high-velocity flow out of the culvert under flood conditions and reduce its velocity before the floodwaters discharge into the downstream creek.
Construction truck movements up and down narrow unsealed track to site will cause unacceptable noise, dust and erosion.	A Rotec conveyor system was imported from the USA to deliver RCC and conventional concrete from a temporary batching plant near the reserve edge to the basin wall. The conveyor zigzagged its way between the trees, avoiding the need to remove any large trees.
Construction noise will disturb residents living in nearby houses.	Vehicle access to the construction site was through an adjoining industrial area. Construction was limited to daylight hours five and half days per week. A 24-hour per day 'hot line' operated by a specialist consultant received and dealt with all inquiries and complaints.
Need to construct basin wall quickly to minimize risk of flooding of construction works by rises in creek.	Precast concrete panels acted as formwork for placement of the RCC in layers and as the permanent external facing of the basin wall.
Concern about safety of basin wall in an extreme flood.	Basin wall has a central spillway, with training walls on either side, capable of passing the probable maximum flood. Steps on downstream face help dissipate energy of overtopping floodwaters. Design was approved by state agency responsible for dam safety.
Significant areas of bushland will be cleared to provide for stockpiles, storage and batching.	Areas able to be cleared strictly limited by contract with stiff penalties for non-compliance. RCC aggregate blended off-site. Materials delivered to site only when required.
Hikers may be trapped in basin by quickly rising floodwaters.	Studies showed rate of rise of floodwaters increased, but not unduly hazardous. Creek-bank walking track upgraded. Bypass walking track constructed up and around basin wall. New footbridge built over creek. Signs erected indicating egress routes.

port and three volumes of specialist working papers, each of about 300 pages.

Because of strong opposition to the project from the small, but determined group, and the possibility that its decision could be appealed in the courts, city council was careful to allow everyone to have a say. The proposal was publicly exhibited and comments on the proposal and the EIS were invited. Letters of objection were received from 25 households and letters of support from 19. Council held a public meeting to discuss the proposal. About 60 people attended — equal numbers for and against the proposal. Council also had a retired judge conduct a mediation conference at which groups supporting and opposing the project put their case; but no compromise could be found.

At about this time the trust was advised of a similar large flood detention basin in the Adelaide Hills of South Australia, which temporarily inundated natural bush. An inspection by council members and senior staff showed healthy mature trees growing in areas subject to regular inundation and no significant infestation by weeds.

Finally, after seven months of comment and deliberations, the trust's application was approved unanimously by the council, subject to over 100 conditions previously agreed upon. Because government funding was required to help finance the project, the EIS was also submitted to the Commonwealth Government and, in due course, approved.

Construction

To avoid needless delay in commencing construction, detailed design plans had been prepared whilst the EIS was being finalised, before development consent was granted.

Within a month of development consent, detailed design plans were completed and tenders for construction called. Within three months, a $6 million contract to construct the basins wall was awarded and a consultant appointed to supervise the construction. The other environmental and structural measures, which formed part of the overall Stormwater Management Strategy, were carried out under separate contracts or by direct trust supervision of contractors. Construction was subject to severe environmental conditions reflecting the environmental sensitivity of the site, all monitored closely by the relevant agencies.

The main difficulty experienced during the 12-month construction period was frequent wet weather for four months. This caused the exposed excavation to be flooded 20 times, requiring exhaustive cleanup after each flood event.

Some of the more successful construction features were the pre-blended aggregate, the RCC mix, the conveyor system used to deliver RCC to the basin wall and the precast panels used both as formwork and the permanent facing of the wall.

Upon completion of the basin wall in July 1996, all disturbed areas were restored using previously salvaged plants, mulch, topsoil and rocks.

Other measures carried out as part of the overall project included:

- an alternative walking track around the basin wall site, incorporating a new timber bridge over the creek, a set of steps down a sandstone rock face and a formal viewing area;
- detailed vegetation transect and creek cross section surveys against which future changes can be assessed;
- removal of all weeds from the 10-hectare basin impoundment area and regeneration with suitable native plants, then maintenance for at least five years;
- extensive creek bank stabilisation to allow four-wheel drive vehicle access to the basin wall for maintenance;
- testing of water quality upstream and downstream of the basin wall site before and during construction;
- construction of a CDS (continuous deflective separation) pollutant trap and sediment traps on gullies leading into the reserve; and
- survey, trial excavation and ongoing monitoring of several rock shelters with Aboriginal archaeological potential within the basin impoundment area.

Conclusions

The largest flood detention basin in New South Wales, Australia, has been constructed in a degraded, environmentally sensitive bushland reserve a few kilometres north of the Parramatta central business district in western Sydney. The project not only addressed flooding, but also deteriorating water quality and bushland degradation. The local council approved it after exhaustive studies showed that a large basin was the only feasible way to cost-effectively achieve the flood mitigation objectives and that any adverse impacts on the bushland could be avoided or minimised. The environmental assessment undertaken was undoubtedly the most comprehensive ever carried out for a stormwater project in New South Wales.

The project illustrates the changing nature of urban stormwater control projects: the comprehensive investigation of all possible impacts, the detailed evaluation of alternatives, the community involvement, its multi-objectives, the strict environmental controls and the use of new construction techniques to minimise environmental harm. The increasing requirements for such projects mean that, in future, their proponents will have to accept the considerable challenges involved, and allow the necessary time frame and budget.

Can a Steel Plant be Clean?

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Introduction

This paper discusses stormwater management, and in particular stormwater quality control, from a heavy industrial site located on the upper reaches of the Manukau Harbour, in Auckland, New Zealand.

Founded in 1962, Pacific Steel Ltd., a business unit of Fletcher Challenge Steel, is New Zealand's second largest steel manufacturing plant, and its largest recycling operation. The plant processes 200,000 tonnes of scrap steel including some 60,000 car bodies annually to produce a range of wire rod and reinforcing steel bar products. The Pacific Steel site covers some 20 ha (45 acres) and includes both steel manufacturing and scrap metal recovery operations. Prior to development, the site was under pasture.

The site is located on the southern shores of the Mangere Inlet, in the upper reaches of the Manukau Harbour (Figure 1). The outer Mangere Inlet is recognised as important for marine vegetation, and as a high tide roost for thousands of international migratory and New Zealand endemic wading birds, including a number of threatened species.

Significant improvements in the quality of Pacific Steel's stormwater discharge have been achieved over the past 5 years following the construction of a stormwater pond/wet

Figure 1. Map location

and treatment device, and the implementation of a comprehensive stormwater management plan for the site.

The stormwater treatment device is used as a demonstration site for stormwater treatment from a heavy industrial area in the Auckland Region, and consequently has been extensively monitored by both Pacific Steel Ltd. and the Auckland Regional Council (ARC). This paper outlines the results of this monitoring. The paper also highlights how the site's stormwater management practices have improved, particularly in response to the results of this monitoring. Finally the paper discusses the practical experiences gained in the operation of a stormwater treatment device within a heavy industrial site.

New Zealand's Statutory Environmental Framework

By way of background, New Zealand's environmental statutory framework is set out in the Resource Management Act 1991 (RMA). This is an omnibus piece of legislation having consolidated some 56 pieces of legislation relating to the environment. The purpose of the RMA is to *"promote the sustainable management of natural and physical resources*." The RMA also sets out the powers, duties, and functions of the various authorities responsible for implementation of the Act.

The ARC is the environmental protection agency for the Auckland Region. With respect to stormwater management, the ARC has responsibilities for minimising natural hazards such as flooding, and for stormwater quality issues.

The RMA is an effects-based piece of legislation, and requires the effects, both positive and negative, of any proposed activity to be identified prior to commencement of that activity. Once identified, the RMA requires that any adverse effects are, as far as possible, avoided, remedied, or mitigated.

While focusing on the effects of a given activity, the RMA also enables a "best practical option" (BPO) approach to be taken to the discharge of contaminants to air, water, or land, or an emission of noise. This BPO approach is defined as the best method for preventing or minimising the adverse effects on the environment having regard to, amongst other things:

1. the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects
2. the financial implications on people and society
3. the effect on the environment of that option when compared to other options
4. the current state of technical knowledge and the likelihood that the option can be successfully applied

ARC Stormwater Management Program

The ARC initiated its stormwater quality control programme in the late 1980s, in response to growing concerns over the impact contaminated urban runoff was having on both the freshwater and marine receiving environments.

Auckland is characterised by the fact that it sits astride two major harbours. Its freshwater catchments are generally short and steep, with most discharging to low energy estuarine and upper harbour areas. Any contaminants that wash off the land, therefore, are rapidly deposited in these low-energy marine environments, and accumulate with time.

Given the variability of stormwater quality through time and from different land uses, the ARC adopted a "best practical option" approach to its management and, in particular, the treatment of stormwater.

At an early stage in the development of the stormwater quality control programme, the ARC prepared design guidelines for stormwater treatment devices (ARC 1992). Through this design manual, guideline removal efficiencies for stormwater treatment of 75% for suspended solids are promulgated. The ARC also requires all new development or redevelopment to address stormwater quality on a case by case basis (ARC 1995).

The ARC has established, in conjunction with a number of interested parties, a range of representative stormwater treatment demonstration sites, from which to monitor the effectiveness of a range of treatment devices under Auckland conditions. In addition to monitoring their effectiveness, the ARC has used these devices to undertake research to further characterise and quantify stormwater related impacts in the Region. One such site has been the Pacific Steel pond/wetland described in this paper.

Pacific Steel Ltd. - Stormwater Management

Historically, stormwater from the site was collected and discharged, largely untreated, via three stormwater outlets (Figure 2).

Following detailed investigations in the late 1980s, a stormwater treatment pond was commissioned in 1992, designed to treat runoff from the entire site up to a 1-in-5-year duration storm flow. The pond is located in the south-western corner of the site, and discharges via a single outfall to the "southern inlet," a small tidal arm of Mangere Inlet (Figure 3). The retrofitting of the stormwater treatment pond, described in more detail below, was accepted at the time by the ARC as the best practical option for stormwater quality control for the site.

In addition to the construction of the treatment pond, Pacific Steel Ltd. has introduced a number of day-to-day site management measures under the auspices of a stormwater management plan. The plan is designed to manage the site's stormwater system and minimise the initial contamination at source. It establishes protocols and sets frequencies for a range of site practices, such as regular storm drain inlet cleaning, street sweeping and dust suppression, installation of waste handling facilities,

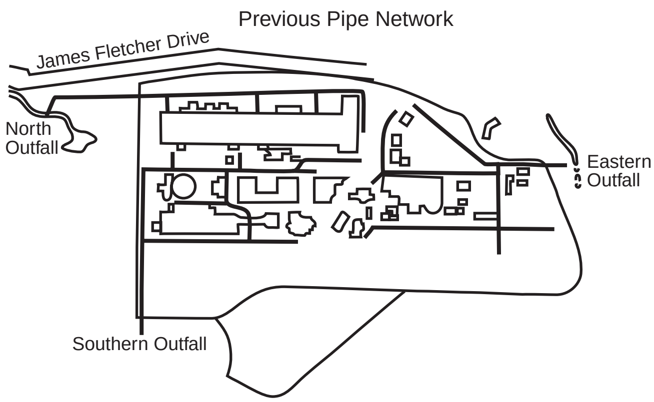

Figure 2. Previous stormwater network.

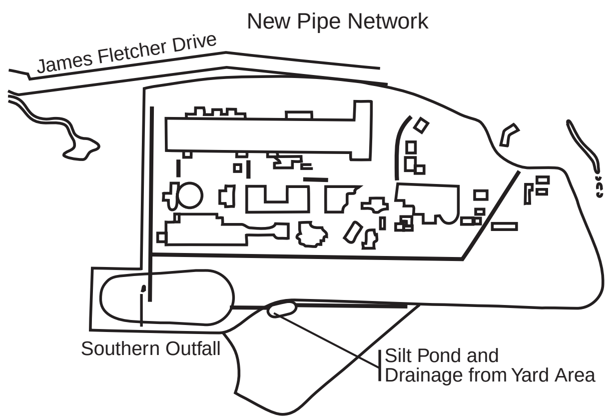

Figure 3. Current stormwater network.

wastewater audits, staff training, and emergency spill response plans. The implementation of the stormwater treatment and the management plan has dramatically increased the awareness of workers on site to stormwater related issues.

Sources of Contamination

The principal types of contamination of concern include: sediment, oils and grease, and a variety of heavy metals. Of the 20 ha site, some 45% is covered by paving, 20% by roofs, and the remaining 35% by stone covered storage yards.

Given the nature and activities on site, sources of potential stormwater contamination are varied and include:

1. Runoff from roads and roofs
2. Steel scrap stockpiles
3. Steel making waste stockpiles
4. Car shredder waste
5. Steel manufacturing (dust and fumes)
6. Truck washes

Typical contaminant concentrations in the site's runoff are shown in Table 1.

The variation in stormwater quality inflow to the pond, as outlined in Table 1, stems largely from the site conditions and the prevailing weather conditions. The 1990 results characterise stormwater runoff from the southwestern part of the site, which did not include runoff from the dirtier scrap recovery areas. Similarly the 1992 result characterised stormwater from two-thirds of the site, again without some of the scrap recovery area contribution. The 1994-1996 results represent the average stormwater quality as determined by monthly grab samples over that period. This sampling would have encountered a range of climatic conditions and is considered to represent the longer term average inflow concentrations for the site. As with the 1992 results, the 1997 results are the average inflow concentrations from sampling of specific storm events.

The variability of contaminant inflows and the influence of individual storm events is highlighted. A more detailed analysis of the long term monthly data has suggested that the inflow contaminant concentrations are reducing with time (ARC unpublished data). This is principally attributed to the improved site management practices carried out under the Stormwater Management Plan. The performance of the pond itself is discussed below.

Treatment Pond Design Characteristics

The treatment pond incorporates a permanent pond and a constructed wetland, as well as an oil trap and an emergency overflow (Figure 4). The pond was designed in accordance with standard stormwater management practices. The pond is some 200m long and has an overall volume of some 4,750 m^3, with an additional live storage of approximately 4,200 m^3. This volume is in excess of that required to meet ARC's guideline of 75% suspended solids removal (i.e., approximately 4,450 m^3). Total cost of the stormwater pond and site upgrade was in the order of $NZ 1M in 1992 ($US 0.6M).

The treatment device was initially commissioned in a staged manner as the re-routing of the site's drainage system took place. It was intended that only stormwater and emergency cooling water overflows pass through the pond. However, recent work related to PCB contamination in the outflow of the pond has identified other waste streams, such as truck wash effluent, which is also discharged to the pond. The impact of these additional waste streams on overall pond performance is currently being investigated.

Operational Experience With Treatment Pond

Experience to date has shown the pond to be effective at removing suspended sediments and other contaminants in the site's runoff. The pond is trapping an average of 3

Table 1. Typical Pacific Steel Ltd. Stormwater Contaminant Concentrations, as Measured at the Inlet to the Stormwater Treatment Pond through time (g/m^3).

Parameter	1990[1]	1992[2]	1994-1996[3]	1997[4]
Suspended solids	19	101.1	77	210
Total Oil and Grease	11	-	35	-
Copper (total)	0.018	0.14	0.14	0.48
Zinc (total)	0.18	1.6	2.94	7.4
Zinc (soluble)	0.09	0.2	0.37	0.23

1 Average stormwater quality prior to treatment pond from "cleaner" part of the site (Bioresearches, 1990)
2 Average inflow over six storm events to new pond prior to full diversion of entire site flows (Leersnyder, 1993)
3 Average ARC monthly grab sampling 1994-1996 (ARC unpublished data)
4 Average inflow concentration over four storm events in 1997 (NIWA, 1997)

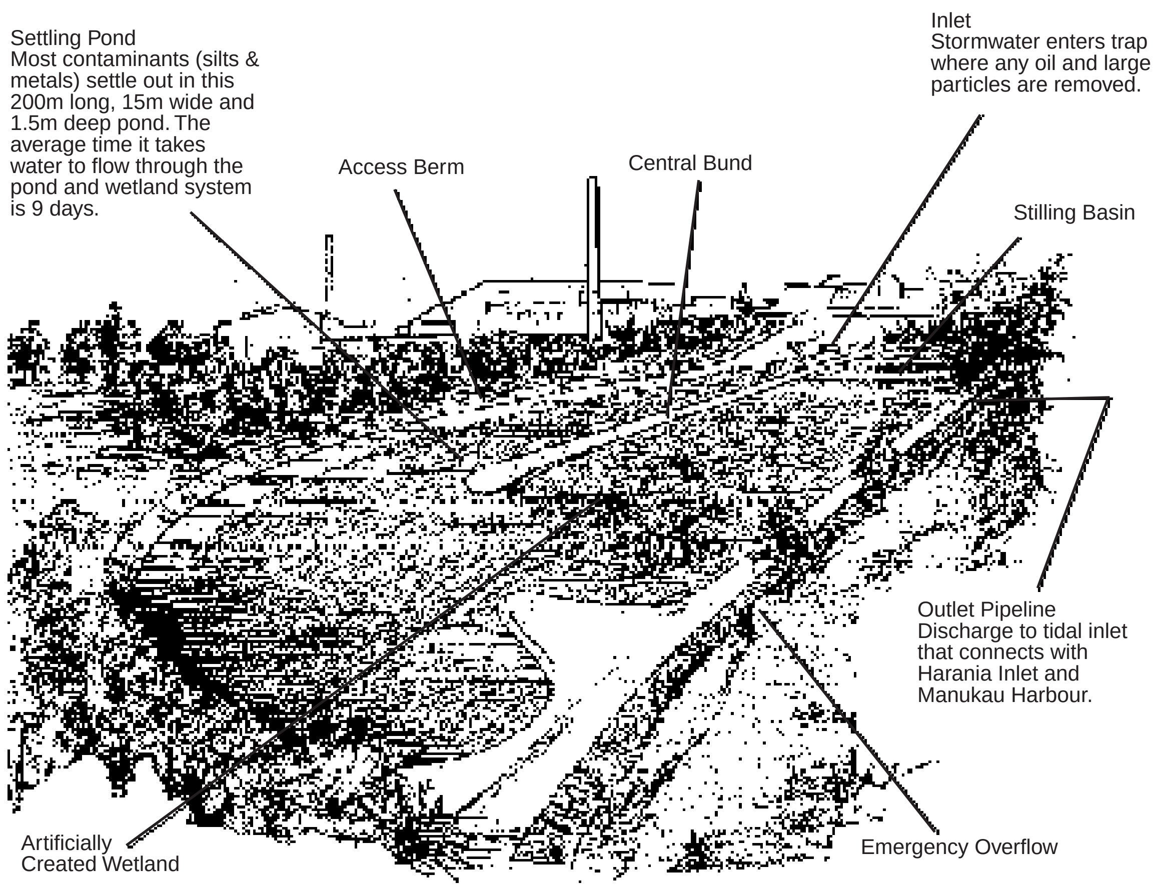

Figure 4. Pacific Steel stormwater treatment pond

tonnes per week of suspended solids which otherwise would have been discharged to the wider receiving environment. In addition, as much of the site is covered, the site's storm drain inlets also trap significant quantities of material which is removed on a regular basis. A more thorough assessment of the pond's contaminant removal performance is given below.

In the course of the 5 years of operation, a number of operational issues and problems have become evident and required addressing. Principal amongst these is the anaerobic conditions which can occur from time to time, turning the pond completely black and foul smelling. It is unclear where the high biological oxygen demand (BOD) water suspected of causing this problem is sourced, although recycled beer cans are suspected. An aeration device has been installed at the inlet of the pond, to aerate the inflow, particularly under low flow conditions in summer. This has largely overcome the problem, although close monitoring of the condition of the pond is required, as a "crash" can occur relatively suddenly.

Water from immediately above the outflow is collected and used on site for dust suppression during dry periods.

Further enhancements to improve sediment removal due to the presence of elevated PCB concentrations, previously undetected and which have come to light due to toxicity screening of the effluent, have recently resulted in the installation of two continuous cartridge filters at the outlet of the pond. This is discussed in more detail below.

Stormwater Pond Monitoring

As indicated, the pond has been the subject of a range of monitoring since its construction. The results of the specific monitoring investigations are outlined below.

Contaminant Removal Efficiency

Intensive performance monitoring of the treatment pond was carried out initially, quantifying the mean concentration reduction and the event mean concentration for various contaminants. This early monitoring estimated similar removal efficiencies for each method (Leersnyder, 1993). Therefore, long-term pond efficiency monitoring has utilised mean concentration reductions on a monthly basis.

Table 2 compares the mean concentration reduction of the pond during the initial two year commissioning period (1992), the subsequent 1994-1996 period, and during recent toxicity studies (1997) undertaken on the pond. The 1992 and 1997 studies sampled pond performance over four individual storm events each.

It is worth noting the relatively high removal efficiencies maintained since commissioning except for soluble Zn. This is in spite of the progressive increase in contaminant loads to the pond since the initial commissioning period. The variability in pond performance is presumably related to the influent variability found in Table 1. However, the long term performance is considered to be acceptable from an engineering feasibility point of view. The toxicity of the inflow and outflows under these conditions and the impact on the wider environment are discussed below.

Table 2. Mean Concentration Reduction, %

Parameter	Initial Commisioning Period (1992)	Monthly Sampling (1994-1996)	Toxicity Testing (1997)
Suspended Solids	80	73	88
Copper (total)	97	79	92
Zinc (total)	92	98	95
Zinc (soluble)	85	78	31
Lead (total)	97	87	94
COD	9	31	ND
Oil and Grease	ND	9	ND

ND - Not Determined

Information relating to the relative contaminant removal efficiencies of both the settlement pond and the constructed wetland are illustrated in Table 3.

Wetland Sediment and Plant Tissue Quality

A range of monitoring investigations were conducted on the wetland component of the treatment device some 3 years after commissioning. These investigations included wetland conditions, the present concentrations of metals and total petroleum hydrocarbons in the wetland sediment, and the levels of metals in the dominant species of wetland plants (Bioresearches 1996). The results are discussed broadly below.

1. Wetland Condition

The wetland was commissioned with six species of plants including:

- Juncus articulatus
- Baumea articulata
- Cotula coronopifolia
- Eleocharis sphacelata
- Schoenoplectus validus
- Baumea juncea

At the time of sampling (3-1/2 years after planting), open water occupied approximately 50% of the total area of the wetland compartment. The wetland has subsequently developed further and now covers almost the total area.

Of the six original plants, it appears the taller plants were the most common, with the tall sedge *B. articulata* having the greatest cover. The smaller sedge *B. juncea* was infrequent, while *C. coronopifolia,* which was expected to occur around the taller plants, was totally absent.

In general, the wetland was in a healthy condition and the species diversity in the wetland had increased mark-

Table 3. Percentage Contaminant Removal Efficiencies Showing the Relative Proportions Removed by Both the Settlement Pond and the Constructed Wetland Components (1994-1996)

	Suspended Solids	Copper	Zinc (Total)	Zinc (Soluble)	Lead	COD
Reduction Inlet to Outlet	73%	79%	98%	78%	87%	31%
Proportion Removed by Pond	93%	89%	82%	52%	87%	94%
Proportion Removed by Wetland	7%	11%	18%	48%	13%	6%

edly with the introduction of opportunistic plants, since commissioning. The wetland is also utilised by birds such as pukeko (swamp hen), shags (cormorants), and ducks. Maintenance was recommended, and subsequently undertaken to remove small colonies of the invasive grass species *Glyceria maxima* and raupo *Typha orientalis* for fear of their rapid spread and potential to exclude other rushes and sedges.

2. Sediment Grain Size

Generally the wetland substrate, which had accumulated since commissioning, was dominated by sediments less than .15 mm in diameter (i.e., very fine sands, silts, and clays). For sediments at the inlet end, the proportion of this finer material was 71.5% of the recently accumulated sediments, while the outlet end sediments contained 79.4% of the fine material. The greater difference was due to markedly higher clay concentrations at the outlet end of the wetland, reflecting the wetland's ability to remove some of the smaller sized particles. Based on these findings, it was calculated that the wetland was responsible for about 9% of the overall sediment removal. This agrees well with the estimates based on the long-term monthly sampling (Table 3).

3. Sediment Quality

The sediment quality information indicates that significant quantities of contaminants are being retained in the wetland, and that during the early life of the wetland, removal at the inlet end would appear to be more rapid. Further testing indicated that all the differences between wetland inlet and outlet sediment concentrations were statistically significant. The percentages of constituents at the outlet end in comparison with those at the inlet end were:

cadmium	23.5%
copper	37.5%
lead	21.2%
zinc	21.9%
total petroleum hydrocarbons	24.5%

With further analysis of the data it became clear that particular areas within the wetland contained higher levels of contaminants than others. The mounded areas introduced in the original design to "baffle" flows, appear to have increased channelling and short circuiting through the wetland. As a result of these findings, more attention is being given to the placement of such structures in future wetland designs.

Wetland sediment quality was compared to sediment quality guidelines for the protection of freshwater aquatic life (Persaud et al., 1992). The results indicate that 50% of the readings were above the lowest effects level (LEL) but below the severe effects level (SEL). While some 47.6% of results were above SEL levels, with the greater exceedance of SEL levels occurring at the inlet end (Bioresearches 1996). At present, there is no indication of abnormal plant growth or dieback which could be attributed to an increase in contaminant levels, and none would be expected given the generally higher level of robustness of these aquatic plants over other aquatic organisms and the limited uptake of contaminants by the plants themselves, as described below.

Although it is not possible to relate sediment contaminant levels to precise effects on the dominant wetland rushes and sedges, changes to the existing biological condition are expected to occur in a progressive fashion through time. A regular programme of monitoring (i.e. sediment levels, tissue levels, and plant vigour) is recommended to quantify this change and provide information on the optimum replacement intervals for the wetland.

4. Plant Tissue Quality

Plant tissue of the wetland plants were analysed for heavy metal concentrations. Table 4 summarises the average levels for all species. The data indicate that the highest concentrations occurred in *Juncus articulatus*, and that total metal loads are dominated by zinc concentrations, which are an order of magnitude higher than the other metal levels measured.

Unfortunately, no baseline data on tissue concentrations was collected prior to planting. However the plant tissue concentrations were compared to "control" plants from the broad geographical area of the original stock, and collected from areas outside of major industrial or other anthroprogenic influences. The assumption is that the "control" plants reflect broadly the metal concentrations of the plants prior to planting. Given these assumptions, the plant tissue concentrations outlined in Table 4 were found to reflect the pattern of concentrations in the "control" plants (Bioresearches 1996).

The highest average increase per species has occurred in the tissues of *Juncus articulatus* and *Baumea juncea* (13 times and 9 times, respectively) while the remainder of the plant species have shown an increase of 4 to 5 times.

Table 4. Average Metal Levels in Stormwater Wetland Plants

Plant Species	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
J. articulatus	0.22	4.03	38.3	31.0	0.13	4.9	516.0
B. juncea	<1.033	1.53	2.7	3.6	0.29	1.1	125.7
S. validus	<0.029	0.73	4.6	0.71	0.024	1.1	91.0
E. sphacelata	<0.015	0.28	4.2	0.85	0.17	1.1	71.3
B. articulata	<0.058	0.43	2.3	1.32	0.016	1.0	39.3
Average	<0.071	1.4	10.4	7.5	0.13	1.8	168.7

With the inlet and outlet areas combined, the average plant metal concentration is only 8% of that found in the sediments; i.e., the accumulation of metals in the sediments is not paralleled by a similar rate of uptake by the plants, and the major mechanisms of metal removal in the wetland appear to be physico-chemical (flocculation, adsorption, settlement, filtration by plant stems) rather than biological.

Influent/Outflow Toxicity Testing

An extensive range of toxicity tests was conducted on both the influent and outflow from the treatment pond (NIWA 1997). The study measured influent and outflow chemical contaminant levels under storm conditions, and toxicity to a variety of freshwater and marine species. In addition, suspended particulate matter (SPM) in the outflow was collected by means of a centrifuge and used to assess the toxicity to sediment-dwelling marine species. Together, these chemical and toxicological components allow a risk assessment to be undertaken for potential ecological impacts on the marine receiving water environment.

1. Water Column Toxicity

The results of the pond water toxicity showed relatively high variability of the influent and outflow toxicity, although there was an observed decline in toxicity across the pond, with the Pacific Steel outflow generally classified as "slightly toxic" to "moderately toxic." In addition, the marine species appeared to be more sensitive than the freshwater, with the greatest response exhibited by a marine diatom and echinoderm.

Dilutions required to mitigate the outflow toxicity ranged from 11 to 46-fold (based on algae and echinoderms, respectively). These results suggest that of the test species currently available the algae and echinoderms, are the more sensitive species for monitoring stormwater impacts on the marine environment of Auckland.

Comparisons between the measured water column toxicity and the expected toxicity based on chemical analysis (totals) showed the measured toxicity to be much lower than expected. Acute (short term) toxic effects would have been expected for both the inlet and outflow on most occasions, based on the guideline exceedances for a number of metals. Similarly, some toxicity was observed on occasions when criteria were not exceeded, suggesting that contaminants other than metals may be contributing to the measured toxicity. Concentrations of ammonia contributed a maximum of 42% to the observed outflow toxicity, based on comparison with published chronic exposure guidelines.

Total and soluble contaminant concentrations are compared with acute and chronic freshwater and marine criteria in Table 5. The acute and chronic metal criteria exceedances over the four storm events monitored are shown in Figures 5 and 6, respectively.

The low measured water column toxicity suggests that the bioavailability of contaminants in both the total and soluble phases is low. One theory is that the high dissolved carbon values in the pond may have markedly reduced the bioavailability of the metals and subsequent measured toxicity on most occasions. Further work is programmed to look at this.

2. Sediment Toxicity

The objective of the sediment toxicity tests was to assess the toxicity of contaminants adsorbed onto the suspended particulate material (SPM), which passes through the pond, on benthic estuarine/marine organisms. Sediment samples were obtained from centrifuging the discharge of the pond.

The first test scenario attempted to simulate a "worst case" scenario appropriate to Auckland of 3 mm of annual contaminated estuarine sediment deposition. The second scenario involved the dilution of the SPM sediment with clean estuarine mud to simulate a likely deposition scenario, whereby discharged material is reworked with the surface layer of the estuarine sediments. SPM dilutions of 5x, 15x, and 50x were used.

The sediment toxicity under the "worst case" scenario showed low acute survival for amphipods and juvenile shellfish. However, given the high particulate carbon and nitrogen levels in the SPM sediments, it is unclear whether the observed toxicity was due to the contaminant levels or the anoxic conditions which developed in the sediments causing them to turn black and smell strongly of hydrogen sulphide. Microscopic examination of the SPM sediments showed high numbers of algal cells and protozoa present.

The acute survival for juvenile shellfish in the second series of tests showed no adverse effects at all dilutions.

Table 5. Total and Soluble Concentrations (g/m^3) of Metals in Water Samples used in Toxicity Tests with Acute and Chronic Exceedances

		Site	Fe Soluble	Fe Total	MN Soluble	MN Total	Cd Soluble	Cd Total	Cu Soluble	Cu Total	Pb Soluble	Pb Total	Zn Soluble	Zn Total
1	Storm Event 1	UI	0.168	0.189	0.0088	0.0583	0.00007	0.00014	0.058^{FM}	0.084^{FM}	0.0121^{FM}	0.1378$^{\mathbf{FM}}$	0.153^{FM}	0.189^{FM}
2		UO	0.082	0.556	0.0004	0.0256	<0.00002	0.00012	0.016^{FM}	0.027^{FM}	<0.0005	0.0045^{F}	0.023	0.031
3	Storm Event 2	UI	0.09	1^{F}	0.0134	0.032	0.00017	0.0003	0.0098^{FM}	0.017^{FM}	0.0024	0.0257$^{\mathbf{FM}}$	0.106^{FM}	0.144^{FM}
4		UO	0.47	1.9^{F}	0.023	0.173	0.00021	0.0004	0.0015	0.002	0.002	0.0063	0.21	0.027
5	Storm Event 3	UI	0.37	2^{F}	0.0996	0.175	<0.00005	0.0021^{F}	0.019^{FM}	0.036^{FM}	0.002^{F}	0.0418$^{\mathbf{FM}}$	0.055^{FM}	0.483^{FM}
6		UO	0.13	1.8^{F}	0.829	0.51	<0.00005	<0.0001	0.0008	0.002	<0.0001	0.0014	0.017	0.04
7	Storm Event 4	UI	0.09	3.5^{F}	0.0068	0.117	<0.00005	0.0003	0.0082^{FM}	0.026^{FM}	0.0035^{F}	0.0643$^{\mathbf{FM}}$	0.088	0.292^{FM}
8		UO	0.35	1.1^{F}	0.0089	0.098	<0.00005	<0.00001	0.0031^{FM}	0.004^{FM}	0.001^{F}	0.004^{F}	0.026	0.032
9	Storm Event1	PSI	0.149	36.7^{F}	0.0097	1.926	0.00042	0.028$^{\mathbf{FM}}$	0.071^{FM}	0.961^{FM}	0.0172^{FM}	2.924^{FM}	0.131^{FM}	19.56^{FM}
10		PSO	0.31	1.97^{F}	0.0007	0.014	<0.00002	0.0005	0.017^{FM}	0.044^{FM}	<0.0005	0.0284^{FM}	0.053	0.238^{FM}
11	Storm Event 2	PSI	0.08	25.5^{F}	0.0061	0.981	0.00019	0.0043^{F}	0.0222^{FM}	0.428^{FM}	0.0063^{F}	0.812^{FM}	0.025	3.1^{F}
12		PSO	0.21	2.7^{F}	0.11	0.159	0.0005	0.001	0.0028^{M}	0.038^{FM}	0.0054^{F}	0.0777^{FM}	0.096^{FM}	0.372^{FM}
13	Storm Event 3	PSI	0.5	73.1^{F}	0.131	2.06	0.00159^{F}	0.0012^{F}	0.0127^{FM}	0.146^{FM}	0.0059^{FM}	0.32^{FM}	0.34^{FM}	1.75^{FM}
14		PSO	0.46	1.8^{F}	0.136	0.184	0.00078	0.0008	0.001	0.008^{M}	0.0041^{F}	0.0208	0.07	0.162^{FM}
15	Storm Event 4	PSI	<0.05	18.5^{F}	0.0111	0.795	0.00021	0.0065^{F}	0.0109^{FM}	0.382^{FM}	0.0025^{F}	0.974^{FM}	0.032	5.1^{FM}
16		PSO	0.11	3.7^{F}	0.123	0.233	0.00028	0.001	0.0056^{FM}	0.061^{FM}	0.0067^{F}	0.164^{FM}	0.145^{FM}	0.679^{FM}

[box]	Exceedance of chronic criteria
F	Freshwater criteria
M	Marine criteria
FM	Exceedance of chronic criteria
FM*	Exceedance of chronic criteria
FM	Exceedance of acute freshwater criteria and chronic marine criteria

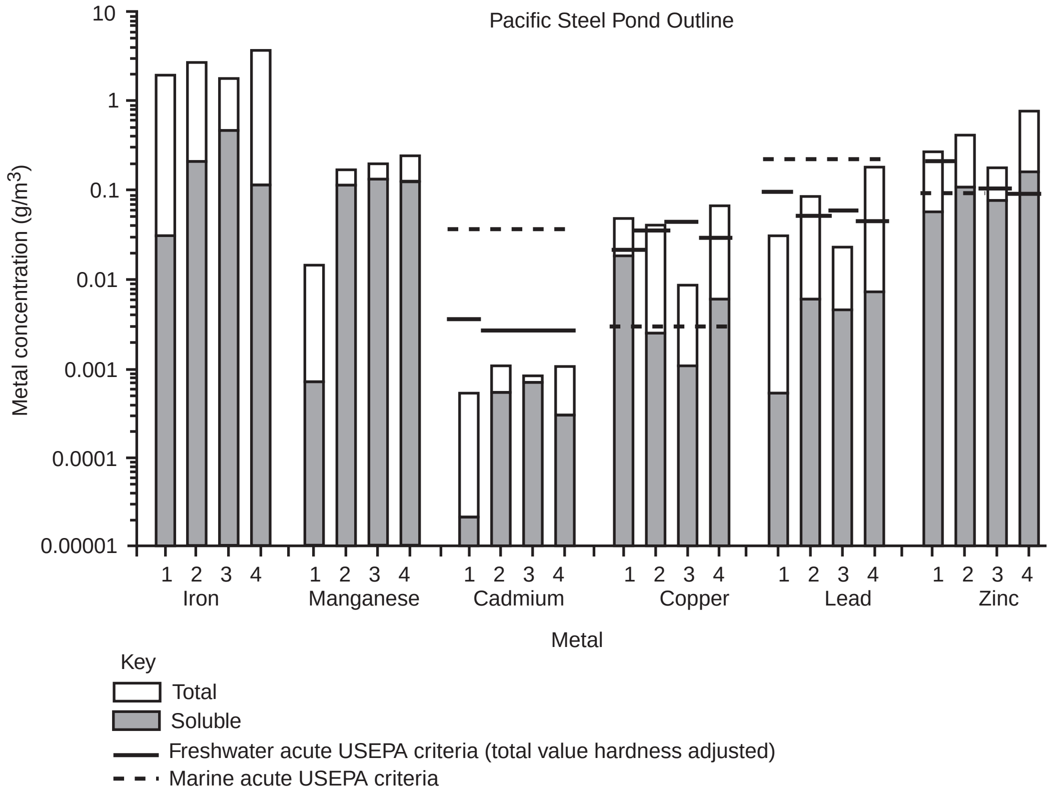

Figure 5. Metal concentrations with acute criteria exceedances in the Pacific Steel pond outlet over four storm events.

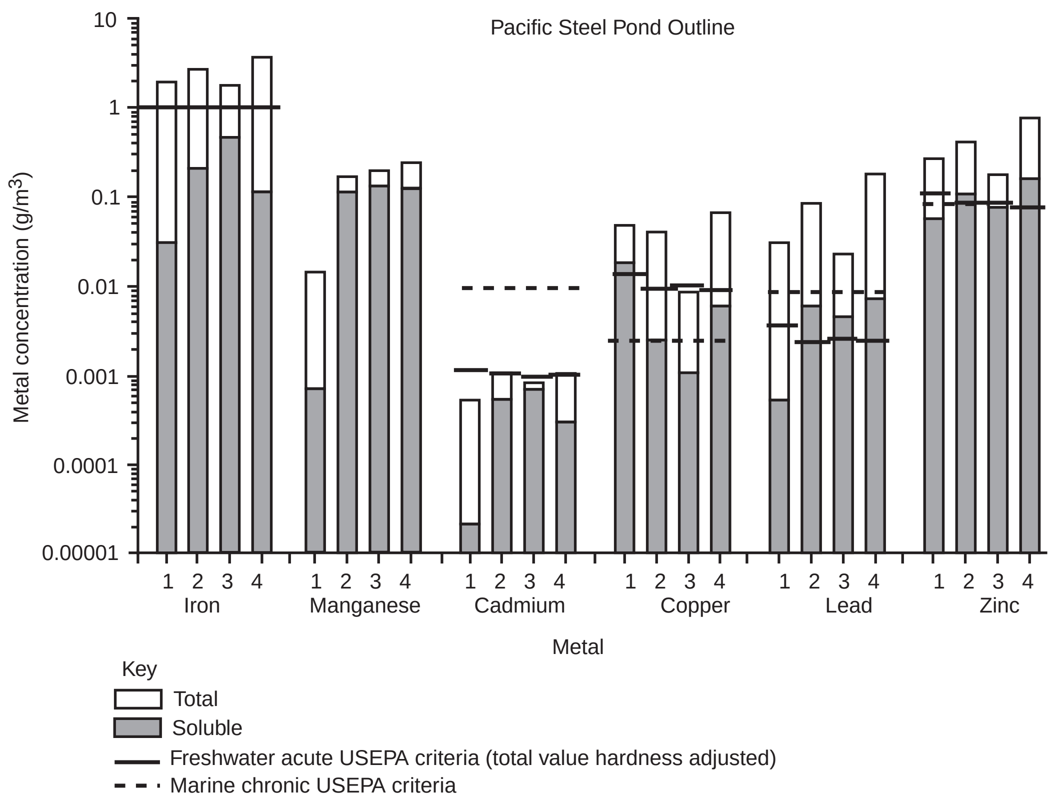

Figure 6. Metal concentration with chronic criteria exceedances in the Pacific Steel pond outlet over four storm events.

The amphipods, however, displayed threshold effects and enabled extrapolation of an EC50 response level of 70% SPM, and prediction of a threshold response (nominal EC10 response) concentration of 10% SPM.

Contaminant levels in the SPM sediments exceeded median effects sediment guideline levels (ER-Ms) for most organic and inorganic contaminants in the pond (Table 6).

Interestingly, Pacific Steel SPM sediments were also relatively enriched in some metals (Cd, Hg, Pb), chlordane, and polyaromatic hydrocarbons (PAHs) when compared with sediment samples taken from within the pond near the outlet. This suggests that there may be higher levels of some contaminants exported from the pond than would be indicated by comparative size fractions in the sediments near the outlet.

The relative toxicity of the various contaminants was compared by dividing the measured SPM concentration by the median effects guidelines (ER-M). The ratios indicate that for Pacific Steel, PCBs followed by DDTs represent the greatest organic contaminant risk, with zinc and lead the more potentially toxic metals. As a result of the elevated PCB concentrations measured during the toxicity investigations, considerable effort has been expended by Pacific Steel to identify the sources of PCBs on site and to prevent them from entering the stormwater system. In addition to the control of PCB contamination throughout the site, a pilot Mikroclean 1 micron nominal cartridge filtration device has recently been installed on the outlet to filter the discharge continuously. The performance of this filtration device is expected to result in a reduction of average suspended solids and PCB concentrations in the discharge of approximately 60%. These measures do not cover the discharge from the emergency overflow, which operates under larger, less frequent storm events.

The measured toxicity responses were in general agreement with the expected effects given the contaminant levels found in the sediments. Given this, the receiving water sediment dilution required to prevent significant adverse effects was estimated based on the chemical data and the guideline exceedence, together with the toxicity results. This suggests that a sediment dilution of up to 115x for sediments leaving the Pacific Steel Pond would be required to pevent significant adverse effects.

Biological Survey of the Receiving Environment

Ecological surveys of the tidal inlet which acts as the receiving environment for the stormwater treatment pond discharge, were undertaken in 1991 and 1995. Samples were collected for benthic invertebrate analysis and descriptions made of the marine vegetation present, as well as the use of the inlet by birds and fishes.

The southern inlet has a former Pacific Steel reclamation on the northern side while the southern side contains a recreational area, disused industrial land, and hospital land at the southwestern corner. Midway along the reclamation boundary is an inlet which receives inflow from a weired creek which drains a residential area. The inlet also receives stormwater from a heavy industrial area

Prior to the construction of the pond, the southern inlet acted as a natural stilling basin for both the Pacific Steel site and the stormwater discharges from the heavy industrial catchment above. The presence of saline conditions are thought to have increased the sediment deposition, and chemical reactions, probably with sea water, had resulted in the formation of precipitates which also settled out. (Bioresearches 1988). Sediment concentrations found in the inlet were elevated in comparison with the Mangere Inlet and the wider Manukau harbour. The inlet was characterised in 1991 as "heavily polluted" (Roan 1991)

In comparison with the conditions found in 1991, by 1995 the volume of freshwater entering the inlet had greatly increased. Contaminants had also declined due to Pacific Steel treatment pond and the closure of much of the heavy industry in the upper catchment. The total number of macroinvertebrate taxa recorded in 1995 was 25, compared to five in 1991. In 1991, the five species identified were typical estuarine organisms; however, the majority of those recorded in 1995 typically inhabit areas which are predominantly freshwater habitats (Bioresearches 1996a).

By 1995, much of the bare mud had been colonised by a variety of wetland/salt marsh plants, including *Cotula* and a variety of rushes. This recolonisation is reinstating a transitional zone more typical of inlets in other parts of the Mangere Inlet. It is also notable that this process is occurring despite the high levels of contamination in the underlying sediments (Bioresearches 1996a).

Following the 1995 survey it was concluded that *"there was no indication that the treated stormwater discharge has had a detrimental effect on the Inlet's biological condition, but has probably led to a more rapid development of a predominantly freshwater fauna upstream from the mangrove zone"* (Bioresearches 1996a).

Conclusion

The quality of the Pacific Steel stormwater discharge has improved dramatically since the commissioning of the stormwater treatment ponds in 1992. The performance of the ponds themselves has matched and even exceeded their predicted design efficiencies. The treatment system has settled down and is operating as expected, although day-to-day management of the entire stormwater system is required to ensure peak performance. At present, there appears to be no observable adverse effect on the wetland plants, and additional performance benefits have been clearly demonstrated from the inclusion of a constructed wetland in the overall stormwater treatment device.

The immediate receiving environment has also improved considerably in the past five years, as a result of both the improvement of stormwater discharges and land use

Table 6. Comparison of Stormwater Sediment Contaminant Levels with Manukau Harbour Levels and Sediment Quality Guidelines (after NIWA 1997).

Stormwater comparison - total metals (mg/kgDW)

Site	C	N	Zinc	Cadmium	Copper	Mercury	Lead	Cumulative ER-M exceedance
Pacific - SPM	15.7	2.2	**7820**	16.7	**653**	**1.54**	**1430**	
Pacific - pond	5.1	0.5	**5635**	*8*	**1702**	0.14	**724**	
Reference Sediment								
Reglan	2.4	0.23	89.8	0.11	21.8	0.093	22	
Harbour site Comparison[c]								
Manukau - W	0.73 (26% mud)	-	86	-	19.4	-	6.1	
ER-L[d]			150	1.2	34	0.15	46.7	
ER-M			410	9.6	270	0.71	218	
Scenario I (undiluted)								
Pacific SPM/ER-M			19.0	1.7	2.4	2.2	6.6	32
Scenario II (diluted 5x)								
Pacific SPM/ER-M			3.8	0.34	0.48	0.44	1.3	6.4

Site	C	N	Tot PCB	DDTs	Chlordanes	PAHs	Dieldrin	Cumulative ER-M exceedance
Pacific - SPM[a]	15.7	2.2	**10753**	*44.2*	**55**	*5353*	**19.5**	
Pacific - pond[b]	5.1	0.5	**10500***	<50	<6	*1900*	<40.1	
Reference Sediment								
Reglan	2.4	0.23	0	0.1	0.1	112	0.1	
Harbour site comparison[c]								
Manukau - W	0.73 (26% mud)	-	2	22	*0.41*	*5311*	0.41	
ER-L[d]			22.7	1.6	0.5	1700	0.02	
ER-M			180	46	6	9600	8.1	
Scenario I (undiluted)								
Pacific SPM/ER-M			59.8	9.6	9.2	0.6	2.4	82
Scenario II (diluted 5x)			12	1.9	1.8	0.12	0.48	16

[a] SPM = suspended particulate matter, sediment collected by centrifuge
[b] pond sediment data from the 1995 survey (Nipper *et al.*, 1995)
[c] Data from Holland *et al.*, (1993)
[d] sediment guideline values from Long *et al.,* 1995, Long & Morgan 1991 (for chlordane and dieldrin)
[*] G. Mills, NIWA, personal communication
Key = **bold** = exceedance of ER-M values; *italic* = exceedance of ER-L values

changes which have occurred in the catchment above. The nature of the receiving environment has changed significantly to one dominated by freshwater inflows, primarily as a result of the Pacific Steel treatment pond discharge. The immediate receiving environment is not displaying any significant adverse effects as a result of the treated stormwater discharges, although should be remembered that the area had been classified as "heavily polluted" in 1992, and that the improvements made to date have to be compared with that impacted status.

With regard to the long-term implications of this treatment device, the results of the toxicity testing paint a somewhat more confusing picture. Measured water column toxicity of the outflow was found to be only slight to moderate, even though the measured contaminant concentrations, and in particular soluble zinc and copper, exceeded both freshwater and marine acute US EPA criteria. The reason for these findings is being investigated further but it is clear that something is reducing the bioavailability of these contaminants. It is also uncertain if this effect on the bioavailability of the contaminants is a long-term phenomena, or whether the contaminant loads discharged from the pond will become available in the future, and potentially give rise to adverse effects in the wider receiving environment.

The measured acute toxicity of the particulate material leaving the pond showed low survival rates for all test organisms in the experiments attempting to test the worst case scenario. However the anoxic conditions which developed during the experiment are likely to have influenced the result. The acute toxicity shown by amphipods with increasing pond SPM sediment concentration suggests that the discharge from the pond may have a longer term impact on the wider receiving environment as contaminant concentration levels build up.

Interestingly, the finding of elevated PCBs in the discharge has led to a range of measures being implemented on site which should see the sediment and associated contaminant levels being discharged decline by as much as 60% in the future. Work is on-going to assess the effectiveness of these measures in the longer term.

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Real World Modelling
A Case Study of the Silver Lake Watershed Project

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Abstract

The past decade has brought an increasing realization that our aquatic resources are better managed at the watershed level. This often requires the application of watershed modelling to provide managers with the information they need for decision making. Once, this required the hardware and services of consultants specialized in the field, along with the associated costs. However, advances in technology have brought computers powerful enough to run such models to the desktop of virtually anyone. Additionally, just as the private sector has gone through the "downsizing era," government has also been pressured to do more with less. These two factors have combined in such a way that staff members from local governments are now being asked to perform these studies. In a perfect world, data would be readily available for such studies, and the modelling would proceed just like the text book examples. Unfortunately, this is rarely the case. Modelers are often faced with data gaps and other problems which may not even come to light until well into the modeling process. This presentation will address these issues in the context of a case study of a watershed management project conducted in the Silver Lake watershed in central Delaware. It is hoped that a review of the problems encountered and ultimate solutions to those problems will be helpful to other "part-time modellers" finding themselves in similar situations.

Background

The Dover Silver Lake (DSL) watershed is centrally located in the state (Figure 1). The 168-acre lake is within the city limits of Dover, the state capitol. However, much of the 20,000-acre watershed is in Kent County, outside the city limits. There are four major sub-basins or "branches" which drain to the lake. The Maidstone Branch proved to be a significant sub-basin in terms of the modelling effort, as will be discussed later in this paper.

The lake and watershed are within the Coastal Plain Region and display many of the problems associated with water bodies in this region. Excess nutrients, particularly nitrogen and phosphorus, coupled with typical low summer base flow conditions have led to blue-green algal blooms from the time the lake was first formed as a mill pond in the late 1700's. Bathymetric, sediment and in-lake water quality surveys indicate that the lake is well into the eutrophication process, occasionally reaching hypereutrophic conditions in the summer months.

The lake's fish community is dominated by less desirable rough fish, such as gizzard shad and carp, which constantly stir the bottom sediments while feeding. This mixing of the water column is further exacerbated by the fact that the lake is a popular boating area and is the only inland lake in the state which still permits water skiing.

These factors combine to prevent the lake from being used to its fullest potential. Sport fisherman bemoan the fact that there are not more game fish to be caught in the lake. Even those that are caught have consumption restrictions due to toxins found in fish tissue samples. Although the city maintains a small swimming and beach area at a park along the lake, it is closed so many times during the summer due to health concerns that the city is considering building a public pool instead. Review of health department records indicates these closings have increased over recent years. Finally, landowners along the lake have to endure the smell and unsightly scum associated with major blue-green algae blooms which inevitably occur every summer.

Although the existing land use is largely a mix of agriculture and woodland, planners have predicted the watershed is slated for population growth of up to 52% and household increases of up to 73% by the year 2020. Since much of this growth will occur outside the water and sewer service area provided by the City of Dover, it is expected that on-site waste treatment facilities in the porous, relatively high water table soils will be a major source of nitrogen loadings to the lake. Sedimentation from active construction sites, fertilizer applications to lawns, and pet wastes are also expected to be significant potential sources of nonpoint source (NPS) pollution as urbanization of the watershed increases. In the fringe areas where development has occurred, bioassessments have already indicated evi-

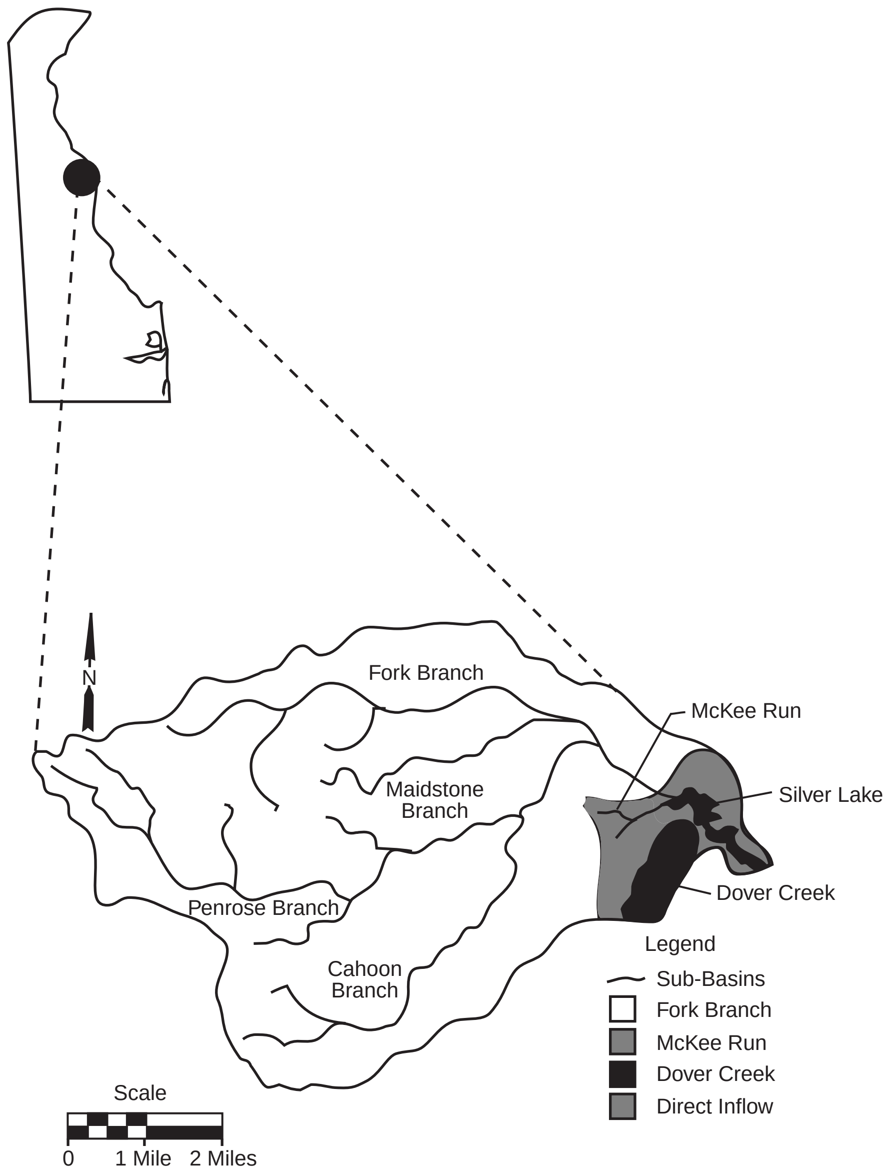

Figure 1. Dover Silver Lake Watershed

dence of impacts to stream systems due to higher stormwater runoff volume and longer duration of flow. Based on these projections, impacts to the lake and streams in the watershed are not likely to subside and may increase.

Initiation of the Modelling Effort

The City of Dover first approached the Department of Natural Resources and Environmental Control (Department) with documented water quality problems in the lake. However, it was recognized that Kent County would have to be a major player involving any recommendations dealing with land use. An advisory committee was formed, with representatives from the department, city, county, environmental groups, builders/developers and other stakeholders. It was decided that a watershed protection/restoration plan was needed to keep the lake from further degradation. An important component would be the development of a watershed model, which would allow decision-makers to assess impacts to the lake based on various policies and recommendations put forward in the plan.

Although a grant was procured from the National Oceanic and Atmospheric Administration (NOAA), it was apparent that there would not be enough funding to contract the modelling to an outside consultant. At this point, the advisory committee enlisted the help of the department to assist in the modelling effort. Department staff felt it would be feasible to develop a "planning level" model, but that a "deterministic" model would require additional resources. It was decided that a "planning level" model would suffice, and the staff were told to proceed. The remainder of this paper will describe some of the goals and methodologies of the DSL modelling effort. Although these have been separated into data issues and model issues for purposes of discussion, the reader should be aware that many of these issues must be addressed concurrently during the modelling effort.

Data Issues

Collection

In most cases, data collection will be the first priority in model development. A thorough review of existing information and data should be done. Sources of such information used in the DSL Watershed Project included:

- Previous studies done in the watershed under the Clean Lakes Program
- An analysis of the lake dam conducted by the Corps of Engineers (USACOE)
- A flood study conducted by the Federal Emergency Management Agency (FEMA)
- Water quality data collected in the watershed as part of the department's responsibility under the Environmental Protection Agency's (USEPA) 305b report
- Soils information from the Natural Resources Conservation Service's (NRCS) soil survey for Kent County, DE
- Land use data from the department's GIS database
- Zoning maps from the City of Dover and Kent County
- Population projections from the State of Delaware
- Topography based on US Geological Survey (USGS) 7.5-minute quadrangles
- Rainfall data from the USGS
- Flow data from the USGS

The last two items are especially important in any watershed modelling effort. As will be discussed, it is important to realize that in most cases, it will be necessary to have two years' worth of rainfall and flow data for the calibration/verification process. The data must also be available in a format which is usable in the chosen model. For example, use of a continuous-type hydrologic model will require rainfall and flow data in a time series format, such as 15-minute interval recordings. Daily totals would not be adequate for use with such models.

Gaps

Data gaps are almost certain to occur in any major watershed modelling effort. Filling those gaps is, of course, dependent on the nature of the missing data. Gaps in rainfall and/or flow data must be addressed quickly, since modelling cannot proceed without such data. As mentioned previously, it is desirable to have two years' worth of data for the hydrologic model. Obviously, if data are not already available and must be collected, the modelling itself must be put on hold until the data become available. Therefore, rainfall and flow data can be considered "mission critical" and should be among the first data collected.

For the DSL Watershed Project, rain gages were placed in two locations within the watershed at project inception to check for spatial and temporal variation in rainfall. In addition, the USGS maintains a time-series rain gage at its main office in Dover. A statistical analysis was conducted on the data from the three gages to ensure that there were no significant differences in the rainfall data. Once this was verified, missing data from one station could be compensated with data from another station with confidence.

Although it was desired to have stream gages located at all four of the major branches feeding the lake, funding only allowed contracting with the USGS to re-establish a gage on the Maidstone Branch; however, the USGS maintains a gage below the Silver Lake dam which measures the flow from the entire watershed and has been in continuous service for more than 50 years.

Although land use data were available for the watershed, they were not a perfect match with some of the land uses used to establish pollutant loadings. Specifically, the initial land use map lumped all agricultural land together. Since pollutant loadings vary considerably among agricultural land uses, it was felt that further breakdown of this category would be necessary. Fortunately, the DSL watershed is immediately adjacent to a sub-watershed which drains to the Chesapeake Bay. The Chesapeake Bay Program (CBP) has done extensive data collection for modelling purposes. Land use data were collected from a remote satellite platform as part of the USEPA EMAP Program. Further, the CBP data had gone through a field truthing QA/QC process. Field investigation indicated that the agricultural land use in the CBP's Choptank Segment was similar to that of the DSL watershed. This made it possible to use data from the Choptank Segment for extrapolation purposes in defining the various agricultural land uses in the DSL watershed.

Ambient water quality data were available from several STORET stations located in the watershed; however, there was very little water quality data collected from runoff during actual storm events. Initially the project team intended to implement a stormwater runoff sampling program to provide this data. However, this proved to be a very costly venture in terms of equipment, lab costs, and staff time. Furthermore, the year the data were to be collected turned out to be one of the driest in many years. It was decided that an alternative was needed. One of the areas studied during the National Urban Runoff Program (NURP) was the Metropolitan Washington, DC area. This study became the basis for the DSL urban land use water quality data. Once again, the Chesapeake Bay Program provided water quality data from agricultural land uses. Locally collected stormwater data were used for verification purposes.

Analysis

One of the most crucial aspects of the modelling process is data analysis. This is the opportunity for the modeller to get to know and understand the hydrologic processes of the watershed. This starts with an analysis of the rainfall. The modeller should compare the data being used for the model with historic data to make sure that there are no anomalies. Data used for the calibration run should also be compared to that used for the verification run. Variation in this data is to be expected. However, if the variation is large, it should be kept in mind that it may be difficult to verify the model with a high degree of confidence.

Arguably, the flow data are the most important and should be analyzed accordingly. The US Geologic Survey does an excellent job of summarizing data from its own gages in its annual "Water Resources Data" reports for both surface and groundwater. This provides a good "first cut" analysis but should be supplemented whenever possible by closer scrutiny of the data itself. In the case of the DSL Project, USGS time-series flow data were imported into a spreadsheet program and graphed so that individual storms could be analyzed. As mentioned previously, there were two gages in the watershed. One was below the spillway of the Silver Lake dam on the St. Jones River, while the other was on the Maidstone Branch, a major tributary draining to the lake.

Although is was desirable to model the watershed as a whole, the available flow data would make this difficult. The St. Jones gage measured the outflow from the lake and therefore represented flow which had been routed through a reservoir. Inflow data to the lake was limited to only one tributary, the Maidstone Branch. Furthermore, the St. Jones gage captured approximately 150 acres of highly urbanized land below the dam spillway which resulted in an incidental peak in the hydrograph prior to the main peak from the reservoir. This incidental peak, along with the reservoir effect made the St. Jones data less desirable from a watershed modelling standpoint. However, visual observation indicated that the flow data from the Maidstone Branch, though lower in magnitude, was clearly correlated to that for the St. Jones. Statistical analysis confirmed this correlation; therefore, the Maidstone Branch was used as a "surrogate" for the DSL watershed as a whole. This eliminated the problems associated with the St. Jones flow data and simplified the modelling process. The relationship with the highest correlation was the "Rv" value or runoff coefficient. This correlation was valuable in modelling the future land uses, as discussed later in this paper.

Analysis of the flow data also revealed some other relevant hydrologic relationships. There were considerable seasonal differences in the flow for similar storm events. For example, a storm on April 14, 1993 having 1.26" of rainfall created a peak discharge ten (10) times greater than a similar storm on July 14, 1993 having 1.50" of rainfall. This was apparently due in large part to the effect that vegetation had on interception and transpiration. It was also no doubt related to greater infiltration losses and available surface storage. Whatever the reason, this has important implications for modelling. If one were to rely only on event-type models to represent the hydrology of such a watershed, the results may differ significantly from reality.

Another important hydrologic relationship is the ratio of the surface runoff to the base flow. A manual separation of one year's flow data from the Maidstone Branch revealed that the base flow actually accounted for approximately 50% of the total flow. This also has important implications for the modelling. From a quantity standpoint, the model must have the capability to differentiate the surface flow and base flow in order for a true calibration to be accomplished. From a quality standpoint, the capability to account for the base flow is essential to estimate loadings from soluble constituents such as nitrogen.

Uncertainty

One of the most difficult tasks to deal with in any modelling effort that attempts to predict future impacts is that of uncertainty. For the DSL Project, there were two areas of uncertainty which had to be addressed: future land use and the hydrologic response due to this change in land use. While zoning maps often provide some basis for determining future land use, the unincorporated areas of the watershed were zoned almost entirely as agricultural-residential with an average density of 1 unit/acre on the existing maps. To complicate matters, the City of Dover and Kent County were both in the midst of updating their comprehensive plans, which would not be finalized until after the watershed project was scheduled to be completed. Although planners had predictions for population growth through the year 2020, the actual land use mix associated with that growth was anybody's guess. After wrestling with this dilemma for some time, staff decided to develop five alternative build-out scenarios of increasing density. The mix for these build-out scenarios was based on land use mixes observed in adjacent, more highly urbanized areas. Alternative 3 was considered the most likely build-out scenario for the watershed and consisted of the following land use mix:

- 40% undeveloped
- 25% low-density residential
- 20% medium-density residential
- 10% high-density residential
- 5% commercial/industrial/institutional

The various build-out scenarios, of course, provided the basis for modelling future impacts to the lake, both in terms of water quantity and water quality. Predicting changes in hydrology is one of the strengths of event-type modeling. However, for continuous-type modelling, some input parameters are used for calibration purposes that are not strictly based on physical characteristics of the watershed. Calibrating to an unknown condition is tenuous at best unless one has considerable experience with that model. Fortunately, one of the flow relationships was of value in overcoming this obstacle. As mentioned previously, the strongest correlation found during analysis of the flow data was the runoff coefficient or "Rv" value. This is merely the ratio of the runoff (r) to the precipitation (p) and can be expressed mathematically as follows:

$$Rv = r/p \qquad (1)$$

This relationship was also examined during the NURP study using runoff data collected from the various study areas. Researchers further found that the runoff coefficient was related to the percent imperviousness (I) in the watershed. A regression analysis resulted in the following equation (adjusted $R^2 = 0.71$):

$$Rv = 0.05 + 0.009(I) \qquad (2)$$

Since this relationship ties the runoff with the percent imperviousness, the DSL Project staff were able to use it as a basis for calibrating the continuous hydrologic model for the future build-out scenarios.

Variability

As anyone who has worked with water quality data is aware, there is a tremendous degree of variability in such data. While it is generally accepted that most constituents found in stormwater runoff exhibit a lognormal distribution, it still takes a relatively large data set to characterize local conditions within a comfortable level of confidence. This proved to be cost-prohibitive in the case of the DSL Project and was a major consideration in the staff's decision to develop a "planning level" model as opposed to a deterministic model. Statistical methodologies and Monte Carlo simulations are an alternative, but still require a high degree of confidence in the distribution function. In the end, a simple approach using low, median, and high values was used for the water quality constituents. This approach was also used for analyzing the effects of Best Management Practices (BMPs) in the watershed based on low, median and high removal efficiencies. A matrix was then developed for the various build-out scenarios, constituent loadings and BMP removal rates. From this, it was possible to assess impacts to the lake based on worst case, best case and most-probable case scenarios.

Model Issues

Decision

The decision as to whether to do watershed modelling should not be taken lightly. Modelling is a labor-intensive undertaking, requiring a considerable commitment of staff resources. In most cases, the time required for such an effort will be underestimated. Alternative methods should be explored whenever possible. Results from other watershed studies in the area may be just as valid for planning purposes. This could preclude having to do modelling altogether. In any case, modelling should be viewed as a "least preferred option" for assessing a watershed.

Selection

If the decision has been made to proceed with a modelling effort, the next step is to determine which model to use. This is usually based on what aspect the watershed study is focused on. However, in some cases the choice of a particular model may be predicated on the available data. If time series flow data are not available, for example, some models may not be an option. The capabilities of the modellers must also be considered. Models range in complexity from simple regression formulae to statistical models to computer programs capable of doing very sophisticated hydrologic simulations. There is, unfortunately, no single model currently developed which can be thought of as providing "one-stop shopping." Some models, for example, are geared to event-type modelling for assessing flooding and water quantity impacts. Others operate in continuous mode for assessing water quality impacts. Some model runoff conditions, others model receiving water interactions. The models used for the DSL Project were as follows:

- Hydrologic Models

  TR-20 (NRCS) - Single-event mode only, synthetic rainfall; used to estimate runoff associated with major storms (i.e., 10-YR, 100-YR, etc.) for FEMA floodplain studies.

  PCSWMM (EPA) - Single or continuous mode, actual rainfall; calibrated against actual flow records to simulate hydrologic processes for Maidstone Branch sub-watershed.

- Hydraulic Model

  HEC-RAS (COE) - Used to estimate water surface profiles for FEMA floodplain studies.

- Water Quality Models

  PCSWMM (EPA) - Used to estimate pollutant loadings for single or continuous rainfall events based on Event Mean Concentrations (EMC).

  Excel (Microsoft) - Spreadsheet program used to estimate pollutant loadings based on both EMCs and Export Coefficients.

- Receiving Water Model

  Vollenweider Model - Regression formula used to estimate the steady state phosphorus concentration in Silver Lake.

- Trophic State Model

  Carlson Trophic State Index (TSI) - Method used to determine the likelihood that the lake displays a particular trophic state (i.e., mesotrophic, eutrophic, etc.).

Calibration/Verification

For hydrologic simulation computer programs such as EPA's Stormwater Management Model (SWMM), it is essential to calibrate the model to local data. If available, a full year's worth of rainfall and flow data in a time-series format would be preferred. The purpose of the calibration run is to make sure that the output from the simulation is consistent with observed data. This is largely a matter of adjusting the various input parameters until the results from the simulation agree with the observed data within an acceptable degree of variance. The modeller must be careful not to adjust the parameters outside the range of accepted values just to get a better calibration. The adage "garbage in, garbage out" certainly applies in this case.

Once the model is calibrated, a verification run should be made with an independent data set. The verification process assures that the model has not been merely optimized to a single data set, but can give consistently realistic results as the input data varies. The calibration and verification process has often been referred to as the "what is" stage of the model.

Prediction

Once the model has been calibrated and verified, it can be used for assessing "what if" scenarios. This is the primary purpose of any major watershed modelling effort. In the case of the DSL Project, future impacts to the tributaries and lake under various land use changes could be assessed, along with potential mitigation methods. Some of the results were as follows:

- Peak discharges, volume of flow, duration of flow, and out-of-bank incidences could all be expected to increase under the various build-out scenarios. The percentage increase depended on the percentage of imperviousness.
- Under the most probable build-out scenario, flow depth increased 9 inches for a storm which under existing conditions was just at bank-full elevation.
- As a result of the hydrologic changes, stream channel erosion would be expected to increase, thus increasing total suspended solids (TSS) loadings to the lake.
- Loadings of total phosphorus (TP) to the lake remained relatively flat with increased build-out.
- Loadings of total nitrogen (TN) to the lake increased slightly with increased build-out.
- Even under a best-case scenario, it was unlikely that the lake would drop below eutrophic conditions.

Validation

A step which is often overlooked in some watershed studies is validation of the model results. This is not to be confused with verification, which is more closely associated with the functioning of the model itself. The validation process is an attempt to assure that the results from the model can be accepted. A model could conceivably be calibrated and verified, yet still yield unacceptable results. The water quality estimates from the models developed for the DSL Project were validated by comparing them to observed concentrations from several STORET stations in the lake. The model results indicated that the average total phosphorus (TP) concentration in the lake for the existing condition would be 0.22 mg/l. This compared favorably to the average observed TP concentration of 0.17 mg/l, and was well within the range of observed values. Thus, staff felt the results from the models could be accepted, particularly for planning purposes.

Conclusions

As environmental managers become more aware of the need to manage water and aquatic resources at the watershed level, supporting staff are increasingly being asked to provide information for decision makers. This often includes the use of watershed modelling. Such was the case for the Dover Silver Lake Watershed Project located in central Delaware (DDNREC, 1992, 1995a, 1995b). Staff were enlisted to model a 20,000-acre watershed for the purpose of preparing a watershed protection/restoration plan. A critique was done at the completion of the project and it is hoped that information gleaned from that critique will be helpful to others finding themselves in similar situations. Basically, it was found that the modelling tasks tended to be grouped as either data issues or model issues. Data issues included collection, gaps, analysis, uncertainty and variability. Model issues were decision, selection, calibration/verification, prediction and validation.

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Water Quality Modeling to Support the Rouge River Restoration

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Abstract

The Rouge River National Wet Weather Demonstration Program (Rouge Project) has taken on the challenge of implementing river restoration efforts in a highly urbanized watershed. The 467-square mile Rouge River Watershed is located in southeastern Michigan, and encompasses 48 communities, including the City of Detroit. A significant number of stormwater and combined sewer overflow (CSO) controls are being installed within the watershed to address Rouge River pollution reduction objectives.

A suite of hydrologic, sewer system and riverine water quality models have been used to address technical questions that have been asked in Rouge River Watershed planning. This paper presents application of four of the models used by the Rouge Project: 1) *TRTSTORM*, 2) *Watershed Management Model (WMM*), 3) *Stormwater Management Model (SWMM)*, and 4) *Water Quality Analysis Simulation Program (WASP)*. The TRTSTORM model predicts annual overflow statistics for various CSO control facilities. A simple pollutant loadings model, the WMM evaluates and communicates the relative impacts of various stormwater controls. SWMM is aiding the development of subwatershed management plans by predicting relative changes in wet weather river response for alternative controls. Finally, the WASP event model predicts the highly transient dissolved oxygen drops caused by CSO discharges, thus the benefits for various levels of CSO control.

The Rouge Project models have been and continue to be an important decision-making aid for the project. In addition, the modeling approach used by the Rouge Project, as well as several specific modeling tools, are transferrable to other urban watershed management projects.

Introduction

The Rouge Project is using four modeling tools to support river restoration efforts in the highly urbanized Rouge River Watershed. The U.S. Environmental Protection Agency (USEPA) sponsored the Rouge Project, in 1992, to demonstrate effective solutions to wet weather water quality problems in urban areas. Under the leadership of the Wayne County Department of Environment, CSO controls and stormwater best management practices (BMPs) are being implemented within a watershed approach which stresses an inclusive process of all stakeholders.

This paper presents an overview of how water quality models are being used to answer technical questions which arise in the Rouge Watershed planning process. Application of four specific models is discussed including each model's role and sample results which illustrate how the model could be applied in other watersheds. Several lessons learned in the Rouge Project modeling effort are also presented.

The Rouge Watershed

The Rouge Watershed encompasses 467 square miles in Michigan's greater Detroit metropolitan area and is home to 1.5 million residents. The Rouge River has been identified as one of the most polluted rivers in the Great Lakes basin. The Lower, Middle, Upper and Main Rouge River branches total 127 miles in length, and comprise one of the state's most publicly accessible rivers.

Multiple pollution sources have led to the gradual degradation of water quality and habitat in portions of the Rouge River and resulted in use impairments. The primary problems include CSOs, nonpoint stormwater runoff, illicit connections, failing septic tanks, stream bank erosion and increased flow variability. The combined effect of these pollutants has led to depressed DO levels, whole-body contact prohibitions, damaged aquatic habitat, fish consumption advisories and poor aesthetics.

One-third of the CSOs in the watershed are being controlled via 11 demonstration CSO basins, several of which became operational in 1997. Performance of the demonstration facilities will be used to determine the appropriate level of control for the remaining CSOs. The watershed has been divided into 11 subwatersheds where advisory groups are forming to address all other pollution sources in a holistic fashion. Numerous stormwater BMPs, recreation and habitat projects have already begun and more are planned.

Modeling Approach

The modeling effort consists of a three-tiered approach. Tier 1 consists of several small area models used to simulate flows, pollutant loads and concentrations from specific pilot projects or localized areas of study such as wetlands, swales, wet detention ponds and individual CSO basins. Tier 2 consists of a simple pollutant loading model and a detailed sewer system model that both simulate pollutant generation by subarea for the entire watershed. Tier 3 is the river models which simulate instream flows and concentrations in the four main river branches, based on the inputs from the Tier 2 detailed sewer system models. Following are four examples of these models in use.

CSO Facility Performance

While the 11 demonstration CSO facilities were in the design stages, the TRTSTORM model was developed to provide some early predictions as to how these basins would perform (Kluitenberg et al., 1994). The model was used to address the following questions:

- How will the proposed CSO facilities, designed to several different sizing criteria, perform relative to presumptive criteria in the USEPA CSO Policy (USEPA, 1994)?
- What annual pollutant load reductions are expected from the proposed facilities?

The TRTSTORM model is a simple hydrologic mass balance model which tracks CSO facility filling, treatment, overflow, dewatering and decanting based on long-term hourly precipitation records. It is a modified version of the U.S. Army Corps of Engineers “Storage, Treatment, Overflow, Runoff Model” (Hydrologic Engineering Center, 1976). The model generates annual performance statistics for flows to the treatment plant (via interceptor), treated and untreated overflows.

The model was used to show that all CSO facilities designed to the demonstration sizing criteria should meet the 85% capture and four overflow per year presumptive criteria in the USEPA CSO policy. The model used assumed treatment efficiencies to determine expected annual load reductions for a number of pollutants at each facility. Figure 1 shows a summary of the predicted annual reduction in biochemical oxygen demand (BOD) entering the receiving water for: one site-limited facility; five basins sized to provide 20-minute detention of a 1-year, 1-hour storm (demonstration size); and two basins sized to capture a 1-year, 1-hour storm (Michigan Department of Environmental Quality (MDEQ) size). The results make it clear that for either of the two sizing criterion, annual load reduction is strongly governed by capture and is fairly insensitive to basin treatment efficiencies.

Pollutant Loading Analysis

The Watershed Management Model (WMM) is being used to estimate annual pollutant loading. In each subwatershed, WMM is being used to address the following questions and to communicate technical findings to stakeholders in an easy-to-understand fashion.

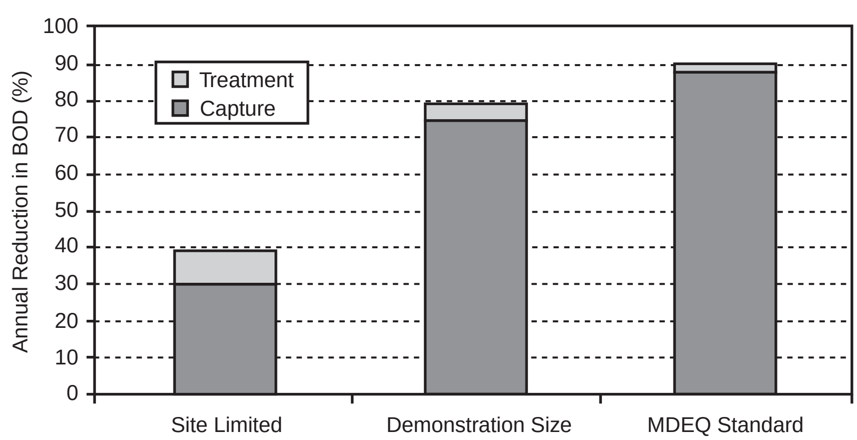

Figure 1. Annual percent reduction in BOD for various basin sizing criteria.

• What are the relative contributions of different pollutant sources in the subwatershed?

• What pollutant load reductions can be expected with various stormwater BMPs and CSO controls?

• How will expected land use changes impact pollutant loads at the bottom of the subwatershed?

The Rouge Project recently completed development of WMM for Windows (Rouge Program Office, 1997) which is being provided to each community for its own use in subwatershed planning efforts. WMM calculates pollutants loads for each source of flow (baseflow, stormwater runoff, CSOs and point sources) in each watershed subarea using annual flow volumes and event mean concentrations (EMCs) assigned to that specific source. The model projects annual pollutant loads by subarea. Various combinations of stormwater BMPs and CSO controls can be selected in specific geographic areas to determine the overall resulting pollutant reductions for a particular management plan.

WMM was used early in the project as a prioritization tool to develop pie charts showing the major pollutant sources in each subwatershed. It was recently used as an analysis and communication tool in three detailed subwatershed management studies. Figure 2 is a sample of WMM results for BOD in the Middle 3 subwatershed, where it was used to show the cumulative effect of two-phase CSO control and two different stormwater management plans.

Watershed Hydrology/River Hydraulics

The Rouge Project has developed a continuous, growing-season model of the entire watershed and the major river branches using the USEPA Stormwater Management Model (SWMM) (Huber et al., 1992). The model is used as the hydraulic driver for the riverine water quality model. It has also been used to assess river hydraulic impacts for issues which arise in the subwatershed planning efforts. Questions it has addressed include:

• How will expected land use changes impact instream hydraulics (flow rates, volumes, depths and velocities)?

• How will proposed CSO control facilities impact instream hydraulics?

• What combination of stormwater BMPs and CSO controls will reduce instream peak flow rates to workable levels for suitable fish habitat?

The SWMM RUNOFF block is used to model the hydrology of all storm sewered areas and areas with natural drainage. An existing SWMM RUNOFF/TRANSPORT model, the Greater Detroit Regional Sewer System Model (Camp Dresser & McKee, Inc., June, 1994), is used to model all CSOs entering the river. Inflow hydrographs from both these models comprise all inputs to the one-dimensional river model, which is simulated with the SWMM TRANSPORT block. A continuous simulation with the full model was calibrated to 6 months of 15-minute data collected with a network of rain and stream flow gages. We assume that these data coincide with a 40- or 50-year analysis.

As part of the Upper 2 Subwatershed Management Study, the model was used to evaluate several scenarios including the cumulative impact of future land use projections, complete CSO control, placement of regional extended dry detention ponds throughout the subwatershed. A fourth scenario involved placement of such ponds at only a few select locations in the subwatershed instead of everywhere. The average increase in peak flow rates for a range of typical storms is shown in Figure 3 for one sample location. The results clearly show that the existing high

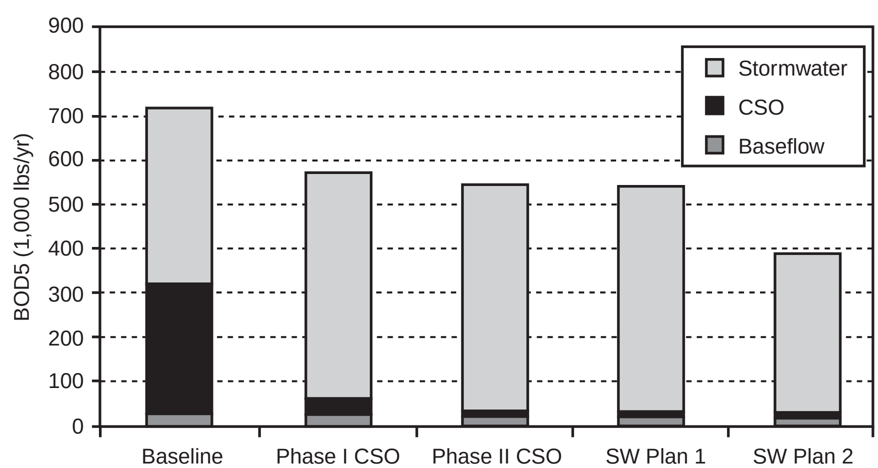

Figure 2. Middle 3 subwatershed WMM model results - average annual BOD load.

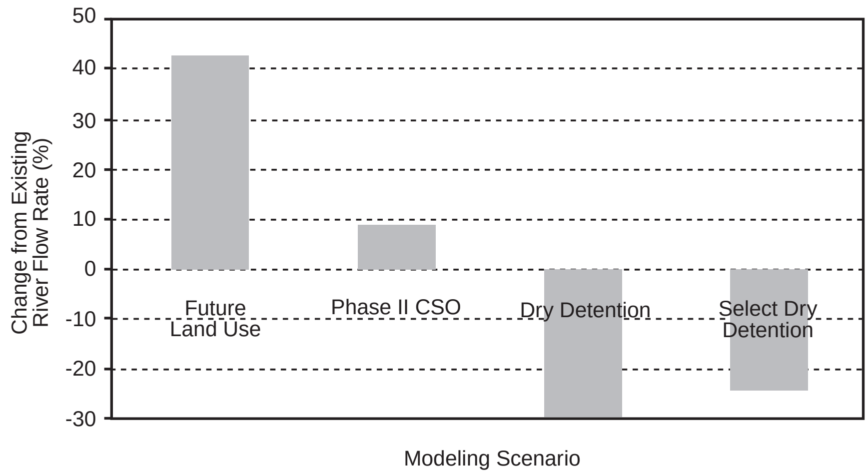

Figure 3. Model river flow rate compared to existing conditions - Upper 2 subwatershed - Bell Branch at Beech Daly.

flow rates and velocities and the resultant bank erosion problems will worsen, but that both types of regional detention could be used to accommodate future land use changes and reduce peak stream flows and velocities below existing conditions.

Instream Water Quality

Building on the SWMM quantity model, a riverine water quality model of the Lower, Middle, Upper and Main Rouge River branches was developed using the Water Quality Analysis Simulation Program (WASP) EUTRO model (Ambrose et al., 1993). While the model was originally developed and calibrated as a continuous model of eight pollutants, it has evolved to its current, primary role as an event model to simulate the CBOD-DO interaction which results from CSOs, including the sudden transitory DO drops which have been observed in the Rouge River. The model is currently being used to address the following questions:

- Will various CSO control alternatives eliminate the transitory DO drops caused by high CBOD in CSO discharges?
- What wet weather DO impairment will remain after all CSO controls are in place?
- How much will dry weather DO improve after controls eliminate most of the sediment oxygen demand (SOD) contributed by CSOs?

The water quality model developed is shown schematically in Figure 4. Stormwater inputs are simulated with the SWMM RUNOFF build-up/washoff algorithms. CSO inputs are assigned concentrations based on the time from when overflow begins, based on typical “pollutograph” shapes from monitoring data. The Rouge Project also developed a new model code linking the SWMM TRANSPORT river hydraulic output to the WASP model. Portions of the model have been calibrated to several heavily monitored wet weather events.

The model was utilized to evaluate two alternative CSO basin sizes in Oakland County on the main branch of the Rouge. For one of the calibrated wet weather events, the instream DO improvement was determined by modeling the impact of complete CSO control with three CSO basins sized to the demonstration criterion. The simulation was also repeated assuming the basins were enlarged to the MDEQ standard sizing criterion. The simulated instream DO shown in Figure 5 illustrates that the demonstration size basins improve the DO sag enough that it no longer falls below the 5 mg/l standard for this event. It also shows the marginal improvement which would have been achieved if the MDEQ basin sizing criterion were used, approximately doubling the size of each of the facilities.

The model of the entire main branch of the Rouge was also used to simulate dry weather DO, which is primarily driven by SOD and reaeration. For the first phase of CSO control and also for complete control, model SOD was reduced to approach that of in-situ SOD measurements made in river reaches which were not CSO impacted. The results in Figure 6 show that CSO controls will provide a significant benefit to dry weather DO, but that some DO impairment will remain in selected river reaches which are somewhat impounded.

Instream performance monitoring began in 1997. The monitoring is intended to show whether effluent from the demonstration facilities will cause any remaining water quality impairment. The water quality event models will be used in the future as part of the analysis of the monitoring results.

Model Findings

Many findings have arisen out of the Rouge Project, several of which the models helped bring to light. Model findings are given below.

- The impairments caused by wet weather pollution are certainly not limited to wet weather periods. In the Rouge this is especially true for the CSO contributions to SOD and the resultant dry weather DO impairment.

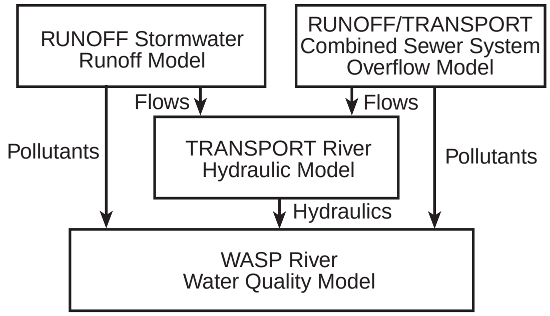

Figure 4. Rouge Tier 3 model schematic.

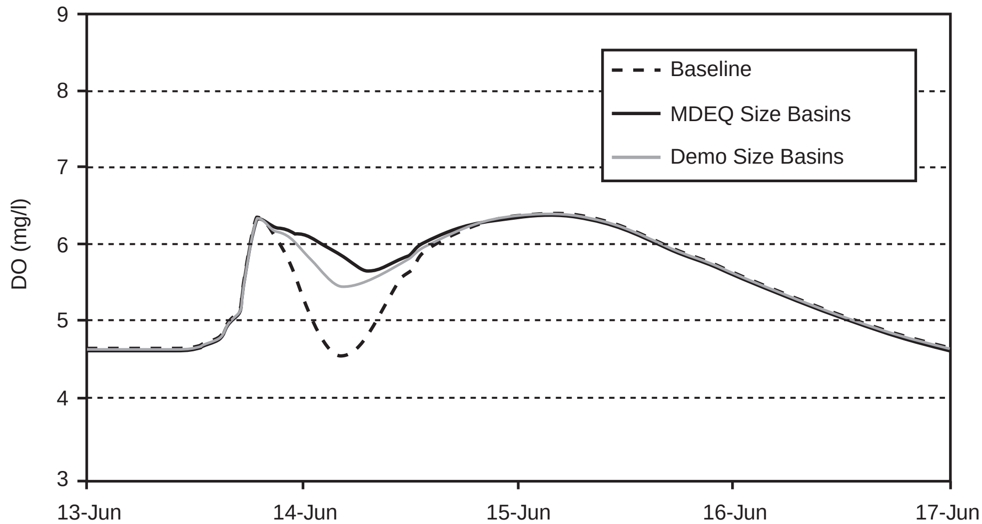

Figure 5. Modeled DO for CSO control alternatives - Main Rouge at 8 Mile Rd.

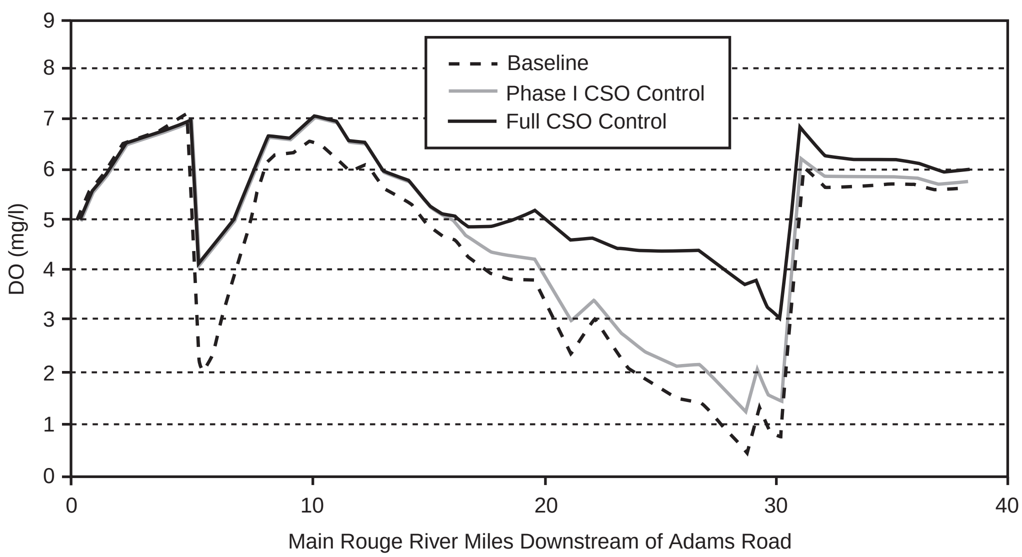

Figure 6. Dry weather model instream DO for June 13, 1994 - Main Rouge from Adams to Greenfield.

- In a predominantly urban watershed, increased stream flow due to urbanization damages aquatic habitat and causes bank erosion, log jams, sedimentation and increased instream solids concentrations.

- Some dry and wet weather DO impairment is expected to remain in the Rouge Watershed after all CSO are controlled, simply due to nonpoint stormwater runoff. Stormwater and CSO must be addressed together in a holistic approach.

- It is expected that the Rouge Watershed CSO basins sized to demonstration criteria will be adequate to eliminate any resultant water quality impairments.

- Rouge Watershed standard practices for on-site detention of stormwater do little to mitigate the development-induced flow increases for small storms, with attendant increased velocities and streambank erosion.

Lessons Learned

Over the course of the Rouge Project modeling effort a number of lessons have been learned about the modeling. Several of the key lessons are:

- If possible, model selection and development should not be performed until the specific questions to be addressed by the model are well formulated.

- A simple loadings model such as WMM can be a good technical resource, but it may be even more important as a tool for communicating technical findings.

- Urban rivers dominated by stormwater runoff present a unique modeling challenge as the difficulty of monitoring nonpoint sources means there are not well-defined inputs for the model.

- Models should not be used to try to answer every question. Many questions can still be answered via analysis of monitoring data.

Conclusions

The Rouge project is successfully using a suite of four water quality modeling tools to address technical questions raised in watershed management planning. The Rouge Project models, modeling approach and findings are a resource that is transferable to other urban watersheds.

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Overview of Urban Retrofit Opportunities in Florida

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Abstract

With the implementation of Florida's State Stormwater Rule in February, 1982, stormwater discharges serving new development or redevelopment were required to be treated by the incorporation of site appropriate best management practices (BMPs) into the project's stormwater management system. The implementation of this program has greatly reduced the impact of stormwater discharges on aquatic resources, especially given Florida's rapid growth which has seen the state's population grow from 9,746,224 in 1980 to an estimated 14,700,000 in 1997. However, stormwater discharges from development existing before 1982 continue to contribute to the degradation of Florida's water resources. This paper will review the institutional framework the state has implemented to address stormwater problems associated with existing land uses. Its primary focus will be to summarize several different types of urban stormwater retrofitting projects that have been undertaken to reduce pollution from older stormwater discharges. For each project, we will review the type and design of BMP, site characteristics, cost, and pollutant removal efficiency.

Introduction

Florida is blessed with a multitude of natural systems, from the longleaf pine-wiregrass hills of the panhandle, to the sinkhole and sand ridge lakes of the central ridge, to the Everglades "River of Grass", to the coral reefs of the Keys. Abundant surface water resources include over 20 major rivers and estuaries along with nearly 8,000 lakes. Plentiful groundwater aquifers provide over 90% of the state's residents with drinking water. Add the state's climate and it is easy to see why many consider the Sunshine State a favored vacation destination and why the state has experienced phenomenal growth since the 1970s. Today, Florida is the fourth most populous state and is still growing rapidly, although not at the rate of 900 people per day (300,000 per year) that occurred throughout the 1970s and 1980s.

Florida's natural systems, especially its surface and groundwater resources, are extremely vulnerable and easily damaged. This is partially the result of the state's sandy porous soils, karst geology, and abundant rainfall. The negative impacts of unplanned growth were seen as early as the 1930s, when southeast Florida's coastal water supply was threatened by saltwater intrusion into the fragile freshwater aquifer that supplied most of the potable water for the rapidly expanding population. By the 1970s, it was becoming all too clear that unplanned land use, development, and water use decisions were altering the state in a manner that, if left unchecked, could lead to profound, irretrievable loss of the natural beauty that brought residents and tourists to Florida. Extensive destruction of wetlands, bulldozing beach and dune systems, continued saltwater intrusion into freshwater aquifers, creation of impervious surfaces and resulting increase in stormwater, and the extensive pollution of the state's rivers, lakes, and estuaries were only some of the negative impacts of this rapid growth.

Fortunately, Florida's citizens and elected officials became educated about these problems and began developing programs to protect and manage the state's natural resources. Florida began serious and comprehensive efforts to manage its land and water resources and growth coincident with the increasing strength of the environmental movement in the nation and the state during the early 1970s. Over the next 25 years, Florida's natural resources management programs have evolved substantially. Collectively, the individual laws and programs enacted during this period can be considered "Florida's Watershed Management Program." In many cases, these laws have been integrated either statutorily, with revisions to existing laws, or through the adoption of regulations by various state, regional, or local agencies. A primary focal point has been the management of nonpoint sources of pollution, especially urban stormwater, since stormwater discharges are responsible for over half of the pollution load entering Florida's rivers, lakes, and estuaries (Camp et al., 1995)

Florida's Stormwater Treatment Program

Research conducted in Florida during the late 1970s characterized stormwater pollutants, provided cost and benefit information on many types of stormwater treatment practices, and determined the importance of stormwater discharges as a major source of pollution. As a result, in 1979, the Florida Environmental Regulation Commission adopted the state's first stormwater treatment requirements. In 1982, the state's stormwater rule was fully adopted, requiring all new development and redevelopment projects to include site appropriate BMPs to treat stormwater. This technology-based program establishes a performance standard of removing at least 80% of the average annual post-development loading of total suspended solids for stormwater discharged to most waters. Stormwater discharges to the state's most pristine waters, known as Outstanding Florida Waters, are required to reduce pollutant loading by 95%. As a result of the implementation of Florida's stormwater treatment program, the impact of the state's rapid growth on its water bodies has been greatly reduced.

With the successful implementation of Florida's stormwater treatment, wetlands protection, and growth management programs to address the adverse impacts of new development, the focus of Florida's watershed management program has shifted to cleaning up "older sources," such as existing urban or agricultural land uses, and to integrating program components to eliminate duplication and improve efficiency and effectiveness. This has led to greater emphasis on more holistic approaches to address cumulative effects of land use activities within a watershed and to a greater emphasis on regional structural controls and the purchase or restoration of environmentally sensitive lands. Key institutional aspects of this changing focus include:

1985 Chapter 403.0893, F.S., is created as the only surviving section of a stormwater management bill that was developed over a ten month process. The bill was an attempt to put into law a cost-effective, timely process to retrofit existing drainage systems to reduce the pollutant loadings discharged to water bodies. The only section enacted creates explicit legislative authority for local governments to establish stormwater utilities or special stormwater management benefit areas. Today, over 80 Florida local governments have implemented a stormwater utility to provide their stormwater programs with a dedicated source of funding.

1987 Chapter 373, F.S., is revised to add a new section, the Surface Water Improvement and Management (SWIM) Act, which establishes six state priority water bodies. It directs the state's five regional water management districts (WMDs) to prepare a priority water body list and develop and adopt comprehensive watershed management plans to preserve or restore these water bodies. The bill provides $15 million from general revenue sources and requires a match from the WMDs. Unfortunately, a dedicated funding source is not established making the program dependent upon uncertain annual legislative appropriations.

1988 The State Nonpoint Source Assessment and Management Plan, prepared pursuant to Section 319 of the Federal Clean Water Act, is submitted to EPA and approved. This qualifies the state for Section 319 NPS Implementation grants which are used for BMP demonstration projects and to refine existing NPS management programs. The delineation of the state's ecoregions, selection of riverine ecoregion reference sites, and modification of EPA's Rapid Bioassessment Protocols and metrics for use in Florida is initiated. This will provide the state with better tools to assess cumulative impacts of stormwater discharges and the effectiveness of stormwater management efforts.

1989 Chapters 373 and 403, F.S., are revised as part of the 1989 Stormwater Bill. The legislation clarifies the stormwater program's multiple goals and objectives; sets forth the program's institutional framework which involves a partnership among DER, the WMDs, and local governments; defines the responsibilities of each entity; addresses the need for the treatment of agricultural runoff by amending Chapter 187, F.S., to add a policy in the Agriculture Element to "eliminate the discharge of inadequately treated agricultural wastewater and stormwater;" further promotes the watershed approach used by the SWIM Program; designates State Water Policy, an existing but little used DER rule, as the primary implementation guidance document for stormwater and all water resources management programs; and creates the State Stormwater Demonstration Grant Program with $2 million in funding as an incentive to local governments to implement stormwater utilities.

1990 Chapter 17-40, FAC, State Water Policy undergoes a total revision and reorganization so that it can be used as guidance by all entities implementing water resource management programs and regulations. Section 17-40.420 (now 62-40.432) is created and includes the goals, policies, and institutional framework for the state's stormwater management program. Key elements are:

- DER is designated as the lead agency with responsibility for setting program goals, providing overall program guidance, overseeing implementation of the program by the WMDs, and coordinating with EPA, especially with the advent of the new NPDES stormwater permitting program.

- WMDs are the chief administrators of the stormwater regulatory program (quantity and quality). They are responsible for preparing SWIM Watershed Management Plans, which include the establishment of stormwater pollutant load reduction goals (PLRGs), and for providing technical assistance to local governments, especially with respect to basin planning and the development of stormwater master plans.

- Local governments are the front lines in the stormwater/watershed management program since they determine land use and provide stormwater and other infrastructure. They are encouraged, but not required, to set up stormwater utilities to provide a dedicated funding source for their stormwater program. Their stormwater responsibilities include preparation of a stormwater master plan to address needs imposed by existing land uses and by future growth; operation and maintenance activities; capital improvements of infrastructure; and public education. They are encouraged to set up an operating permit system wherein stormwater systems are inspected annually to ensure that needed maintenance is performed.

Important stormwater program goals include:

- Preventing stormwater problems from new land use changes and restoring degraded water bodies by reducing the pollution contributions from older stormwater systems.

- Retaining sediment on-site during construction.

- Trying to assure that the stormwater peak discharge rate, volume, and pollutant loading are no greater after a site is developed than before.

- An 80% average annual load reduction for new stormwater discharges to most water bodies.

- A 95% average annual load reduction for new stormwater discharges to Outstanding Florida Waters.

- Reducing, on a watershed basis, the pollutant loading from older stormwater systems as needed to protect, maintain, or restore the beneficial uses of the receiving water body. The amount of needed pollutant load reduction is known as a "Pollutant Load Reduction Goal or PLRG."

With the inclusion of the PLRG concept in State Water Policy, Florida has an institutional framework to begin focusing efforts on the reduction of environmental impacts from existing land uses. While the focus of this paper is on urban stormwater, many projects to reduce stormwater pollution from agricultural activities have been undertaken, including the construction of tens of thousands of acres of wetlands to help restore the Everglades.

The rest of this paper will include short summaries of successful urban stormwater retrofitting projects that have been undertaken in Florida. These are representative of the different types of structural BMPs that are being used to reduce the impacts of urban stormwater discharges on state's waters. However, it is also important to remember that nonstructural pollution prevention programs are also a crucial element of urban retrofitting. Educational efforts, whether signage associated with a structural retrofit project or statewide efforts such as "Florida Yards and Neighborhoods," are essential in reducing "pointless personal pollution" and in gaining the support of citizens and elected officials for stormwater management programs.

Urban Stormwater Retrofitting Project Fact Sheet

Lake Jackson Megginnis Arm Regional Stormwater System
Northwest Florida Water Management District

Watershed Area: 2200 acres

Watershed Land Use:	1191 acres - Low-medium density Residential	213 acres - Roads
	102 acres - High density Residential	207 acres - Open
	469 acres - Commercial	

Project Overview: Studies in the mid-1970s of Lake Jackson in Leon County, Florida, determined that stormwater from the rapidly urbanizing Megginnis Arm watershed and from the construction of Interstate 10 were responsible for the lake's water quality degradation. In 1983, the NWFWMD and the FDER cooperatively designed and constructed, using EPA Clean Lakes grant and state funds, an experimental regional stormwater treatment system. The system consists of a 20 acre wet detention pond with a heavy sediment basin at the inflow, a 4.2 acre sand filter system, and a 5.7 acre, three cell constructed wetland. The pond originally was sized for 150 acre-feet of storage, representing the runoff from a 2.5 inch storm in the watershed. Continued urbanization of the watershed resulted in greater volumes of stormwater, thereby reducing the system's effectiveness. Therefore, the system was enlarged in 1989-90 to increase the storage volume by 31.7% thus providing 173.8 acre-feet of storage, or storage for 1.02 inches of runoff from the watershed. In 1992, the sand filter system was completely renovated, including new distribution pipes and sand filter media. Finally, in 1990-92, over 112,000 cubic yards of sediments which had accumulated in the bottom of Megginnis Arm were removed and the littoral areas of the arm were replanted with native macrophytes and trees.

Project Cost:	Original construction - $2,664,389	Filter renovation - $80,000
	Pond expansion - $253,643	Dredging Megginnis Arm - $990,311
	Educational signs - $19,565	Educational program - $40,000

Educational Component: Educational exhibits were installed at five public boat landings on Lake Jackson to increase public awareness about stormwater pollution, the regional stormwater treatment system, and the dredging project. The NWFWMD created the “Teacher's Guide to Stormwater Runoff in the Lake Jackson Watershed” and a video entitled “In Search of Old Bigmouth” as resource materials for local teachers. These are used in conjunction with a field trip program for local schools which provides students with “hands on” experience in water quality monitoring and the operation of the regional stormwater treatment system. More than 3,000 students have participated in this program.

Project Evaluation: About 6,000 cubic yards of materials were dredged from the heavy sediment basin after three years of operation with additional material removed during the system's expansion. Monitoring data shows that in normal operation, the system can reduce total volume by 30% and reduce loadings by over 90% for solids, 70% for total nitrogen, 80% for total phosphorus, and 50% for orthophosphorus.

Urban Stormwater Retrofitting Project Fact Sheet

Lake Ella Alum Injection System
City of Tallahassee Stormwater Utility

Watershed Area: 157 acres

Watershed Land Use:

13 acres - Residential	15 acres - Open
115 acres - Commercial/Residential	3 acres - Church
11 acres - Commercial	1 acres - Street

Project Overview: In 1985, a lake restoration project was initiated in Lake Ella, a shallow, 13.3 acre hypereutrophic "lake" which receives stormwater runoff from a 157 acre highly impervious watershed. Due to its highly developed and urban watershed, and because of the low permeability of the watershed's clay soils, it was determined that traditional stormwater treatment BMPs could not be used. Instead, chemical treatment of runoff was evaluated using various chemical coagulants including aluminum sulfate (alum), ferric salts, and polymers. Jar tests determined that alum consistently provided the highest removal efficiencies and produced the most stable end product. Consequently, a prototype alum injection system was designed where liquid alum was injected within storm sewers on a flow weighted basis. Standard triplex metering pumps are used as the injection pumps, each individually regulated by sonic flow meters attached to the storm sewer lines to be treated. Many of the smaller storm sewers were combined to reduce the points of discharge into the lake from 17 to ten. Six of these ten inputs, representing 95% of the average flow, are equipped with alum injectors. Alum is pumped from a 6000 gallon alum storage tank into individual one inch PVC underground carrier lines to the point of injection. The alum mixes with stormwater as it travels through the storm sewers, passes through a fine mesh trash trap, and is discharged into Lake Ella. The restoration project also included the removal of 50,000 yds^3 of accumulated sand, debris, and muck from the bottom of Lake Ella and the recontouring of the lake's bottom with a gradual slope toward the outfall control structure.

Project Cost: The city's stormwater utility paid $744,000 for the Lake Ella restoration project, with the alum system costing $200,400. At a cost of $137/dry ton of liquid alum, annual chemical costs for alum injection are approximately $10,000 per year.

Project Evaluation: Pre- and post-alum injection monitoring is summarized below:

Parameter	Before	After	Parameter	Before	After
pH	7.41	6.43	DO	3.5 mg/l	7.4 mg/l
Total Nitrogen	1876 ug/l	417 ug/l	Total Phosphorus	232 ug/l	26 ug/l
BOD	41 mg/l	3.0 mg/l	Chlorophyll-a	180 mg/m^3	5.1 mg/m^3
Secchi Depth	0.5 m	2.2 m	Florida TSI	98	47

Alum sludge accumulation rate: 0.33 cm/yr
Pollutants in sediments are much more tightly bound after alum injection system.

Urban Stormwater Retrofitting Project Fact Sheet

Project Smart - Stormwater Reuse Demonstration
City of Winter Park and the University of Central Florida

Watershed Area: 8.13 acres

Watershed Land Use: 6.84 acres Impervious Residential/Commercial
1.29 acres Greenspace
84% impervious with 42% DCIA

Project Overview: Lake Mendsen is a small urban constructed pond which has been altered significantly over many years and also receives untreated urban stormwater runoff. The primary discharge from the pond occurs to two drainage wells. The demonstration project was implemented to try to reduce the amount of untreated stormwater which is discharged to the pond and ultimately the Floridan Aquifer by detaining a portion of the first flush of stormwater so that it can be used for irrigation purposes or “reuse.”

An area of the pond (approximately 0.7 acres) which receives stormwater from two existing outfalls was isolated from the main pond by the construction of a berm and weir system. The isolated area serves as a surface water reservoir for the irrigation system. Accumulated sediments and invasive exotic vegetation also were removed from the area and the bottom was recontoured. The resulting littoral zone was planted with five species of native aquatic macrophytes. Instrumentation was installed to monitor rainfall, irrigation pumping rates and volumes, and discharge volumes from the reservoir to the main body of the pond.

Project Cost: The entire project cost $143,000, although capital costs for the irrigation pump and system was only about $4,600. Funding for the project was provided by the DER Pollution Recovery Trust Fund ($79,000) and by the city of Winter Park and the University of Central Florida which provided $64,000 in money and in-kind services.

Project Evaluation: A mass balance was performed for the reuse pond over a study period of 358 days. The average irrigation rate for the study period was approximately 1.07 inches per week over the 1.25 acre greenspace. The overall mass balance demonstrated that 55% of the incoming runoff was reused and not discharged into Lake Mendsen. Based on Florida rainfall statistics and stormwater characterization data, this translates into an annual stormwater pollutant load reduction of over 80% for all pollutants. The project also resulted in a real economic benefit. Annualized cost savings for irrigation were calculated to be approximately $3,300 per year, based on the reuse of stormwater versus the use of potable water from the city of Winter Park.

Urban Stormwater Retrofitting Project Fact Sheet

Lake Greenwood Urban Wetland
City of Orlando Stormwater Utility

Watershed Area: 527 acres

Watershed Land Use: 275 acres - Residential 28 acres - Open
210 acres - Commercial/Industrial 14 acres - Water

Project Overview: The Greenwood Urban Wetland was built to alleviate flooding and to treat stormwater runoff prior to discharge to drainage wells which flow to the Floridan Aquifer. The system is designed to detain the runoff from 2.5 inches of rainfall. Approximately 300,000 cubic yards of material was removed to create the system which enlarged the surface area of the “lake” from four to thirteen acres. Weirs were constructed to control water levels and establish three ponds to maximize stormwater detention. The average water depth is 5.1 feet, the storage volume is 66 acre feet, and the hydraulic residence time is 22.7 days. The lakes have a 25 to 30-foot-wide littoral shelf which was planted with over 82,000 plants of ten species of native macrophytes. The lakes are connected by marsh flowways and the system also includes a “riverine floodway” that allows large storms to bypass the lake system. The floodway is planted with seven species of hardwood swamp trees. An upstream sediment/debris basin, pond aeration, and an irrigation system reusing stormwater are incorporated into the design to increase pollutant removal effectiveness. The reuse system allows the City to irrigate the park and the adjacent city-owned cemetery with stormwater instead of potable water, saving the city $25,000 per year. In addition to providing flood protection and stormwater treatment, the 26 acre Lake Greenwood Urban Wetland park includes sidewalks, bridges, and green space passive recreation which is widely used by nearby residents.

Project Cost: $581,000 from the City of Orlando Stormwater Utility.

Project Evaluation: Preconstruction monitoring was conducted from May 19, 1987 through October 13, 1988 to determine the trophic state of Lake Greenwood and to determine the potential loadings discharged to the lake's five drainage wells. The preconstruction Trophic State Index averaged 64 and was highly variable ranging from 12. 5 to 80.8 with five months above 70. After construction, TSI values averaged 57 but no months had values above 66 and variability was less with a range of 36.2 to 66.3. Treatment effectiveness of the system is summarized below:

	TN	NO2	NO3	NH4	TP	OP	Cd	Cu	Pb	Zn
Sed Trap	4%	-76%	4%	-100%	11%	7%	26%	19%	10%	6%
Wetland	11%	8%	-13%	10%	62%	77%	0%	59%	60%	69%

Urban Stormwater Retrofitting Project Fact Sheet

Packed Bed Wetland Filter System
City of Orlando Stormwater Utility

Watershed Area: 121 acres

Watershed Land Use: 75 acres - Commercial; 14 acres - Stadium/parking; 8 acres - Industrial; 18 acres - Roads; 6 acres - Open space

Project Overview: Clear Lake is 360 acres in size and stormwater loadings from its three square mile watershed have led to serious water quality problems. An innovative stormwater treatment system was needed for this basin to both reduce pollutant load and function within a limited area where multiple demands are placed on the use of land. The constructed experimental stormwater treatment train consists of:

- A 3.3 acre off-line wet detention pond with a sediment trap at the inlet.
- Construction of diversion weirs to shunt the first flush to the wet detention pond while allowing the remaining stormwater to bypass the system.
- Construction of 10 packed beds consisting of five crushed concrete and five granite media beds, vegetated with four differing combinations of wetland plants.
- Installation of two pumps to supply water to the packed beds from both the wet detention system during storms and from Clear Lake during dry periods.
- Control valving to allow for varied water flow rates through the packed beds.
- Automated flow meters and composite samplers to allow storm event sampling.

Project Cost: $917,464 including monitoring costs with funding from DEP through the State Stormwater Demonstration Grant Program and from the City's stormwater utility.

Project Evaluation: Monitoring was performed on the effectiveness of the overall system, the performance of the individual beds, and the best flow rate at which to operate the system (30, 60, or 120 gal/min). Analysis of the individual beds showed consistent removal across all beds for cadmium, copper, lead, zinc, total nitrogen, TKN, nitrite, total phosphorus, TSS, VSS, and fecal coliform. Among the remaining parameters, chromium, ammonia, nitrate, orthophosphorus, TDS, and TOC, pollutant removals within bed 6 were consistently low at all three flow rates. Conversely, bed 5 exhibited consistently high removals for the same parameters. The high flow rate was determined to be the best operating rate for the system. Overall pollutant load reduction is presented below:

Parameter	% Removal	Parameter	% Removal	Parameter	% Removal
Cadmium	80	Total Nitrogen	63	Total phosphorus	82
Chromium	38	TKN	62	Orthophosphorus	14
Copper	21	Ammonia	6	TDS	8
Lead	73	Nitrate	75	TSS	81
Zinc	55	Nitrite	-9	VSS	80
Fecal Coliform	78			TOC	38

Urban Stormwater Retrofitting Project Fact Sheet

Bath Club Concourse Stormwater Rehabilitation Project
Town of North Redington Beach, Pinellas County, Florida

Watershed Area: 2.12 acres

Watershed Land Use: Pre-project - 100% Impervious Roadway/Parking

Project Overview: The Bath Club Concourse is a combination roadway and parking lot connecting Bath Club Circle and Gulf Boulevard. Before the project, the Bath Club Concourse was totally impervious consisting of asphaltic pavement. Untreated runoff from the Concourse and its associated drainage area was directed by sheet flow into a single storm sewer inlet and discharged offsite, and ultimately to Boca Ciega Bay.

The objectives of this project were: (1) to maximize the amount of stormwater runoff that could be infiltrated on-site, thereby reducing the annual volume that is discharged off-site without any treatment; and (2) to demonstrate innovative alternative approaches to treating stormwater in highly urbanized areas where land for traditional BMPs is scarce and very expensive. Drainage was redirected toward two new pervious concrete parking areas located in the center of the Concourse. These are separated by an unpaved landscaping island that also provides infiltration. To maximize infiltration of the pervious concrete parking areas, two 150-feet-long underdrains were installed in the eastern half of the project to facilitate the drainage of the subsurface soils immediately beneath the pervious concrete.

Project Cost: Total cost was $147,015 with construction costing $118,380 and landscaping costing $13,345. Funding was provided by a Section 319 NPS grant from DER, the SWFWMD SWIM Program, and the Town of North Redington Beach.

Project Evaluation: The project improvements resulted in a significant reduction of direct discharge of stormwater runoff from the site. Calculations accounting for average annual rainfall and runoff, as well as pore space volume and subsurface water flow, indicate that the improvements caused a 33% reduction in total on-site runoff volume between the pre- and post-project conditions. Further, the volume of surface runoff discharging directly to Boca Ciega Bay was reduced by about 75%. Calculated overall removal efficiencies for the project are based on the efficiency of the underdrain/filter system to remove pollutants and are indicated as follows:

Parameter	Lead	Zinc	TSS	BOD	TP	OrthoP	TN
% Removal	73	72	73	61	49	26	65

Urban Stormwater Retrofitting Project Fact Sheet

Sunset Drive Outfall Stormwater Rehabilitation Project
City of South Pasadena, Pinellas County, Florida

Watershed Area: 49 acres

Watershed Land Use: 21.6 acres - Residential Multifamily
20.1 acres - Commercial
7.4 acres - Residential Single Family

Project Overview: The Sunset Drive drainage basin is nearly fully developed and consists of approximately 55% impervious area. Historically, stormwater was collected and discharged untreated to a local storm sewer which connects to a City of St. Petersburg storm sewer main. This storm sewer main ultimately discharges to Boca Ciega Bay.

The objectives of this project were: (1) to reduce stormwater pollutant loading to Boca Ciega Bay by incorporating an in-line sediment sump/oil and grease skimmer in the Sunset Drive storm sewer system before its junction with the larger storm sewer main; and (2) to demonstrate innovative alternative approaches to treating stormwater in highly urbanized areas where land for traditional BMPs is scarce and very expensive. The sump was designed, to the extent possible, to meet the current rule requirements for this type of system. Due to physical limitations, the design provided for the storm sewer flow to be diverted to the area of an existing greenspace for treatment, prior to being diverted back to the main flow path of the storm sewer. The greenspace, which is adjacent to the bay, was modified into an open, linear wet-sump, which included energy dissipaters and a skimmer baffle. The project also included an attractive boardwalk around and over the facility as well as plantings of salt marsh vegetation in the sump's littoral zone.

Educational Component: The architecture and location of the boardwalk serves to attract pedestrian traffic to the project. Being located immediately in front of City Hall provides an excellent high-profile example of how local government can cooperatively implement measures to reduce stormwater pollution. Several interpretive signs provide information regarding nearshore aquatic plants and animals and the value of stormwater treatment.

Project Cost: Total cost was $115,000 with construction costing $83,131. Funding was provided by a Section 319 NPS Grant from DER, the SWFWMD SWIM Program, and the City of South Pasadena. A grant from the Tampa Bay National Estuary Program paid for the educational signs.

Project Evaluation: The project provides an opportunity to trap and retain sediment and other suspended materials as small as 0.1 mm in diameter. A corresponding reduction in other urban pollutants typically associated with suspended solids such as heavy metals, bacteria, and oxygen demanding substances can also be expected. The sediment load reduction to Boca Ciega Bay is estimated to be approximately 24.5 cubic yards per year.

Urban Stormwater Retrofitting Project Fact Sheet

EMS Stormwater Enhancement Project
Pinellas County, Florida

Watershed Area: 9.24 acres

Watershed Land Use: 9.24 acres - Mixed Use (85% Impervious)

Project Overview: The original stormwater facility was constructed in accordance with regulations in 1990 to provide stormwater treatment and peak attenuation for the county's new Emergency Medical Services (EMS) complex. The facility discharges indirectly into Boca Ciega Bay. The pond was designed to capture stormwater and treat, using a sand filter encased in a concrete vault, the first half-inch of runoff from the entire site. The facility was constructed with 4:1 side slopes, 2 foot average water depth, and a 0.4 foot treatment prism for capturing and filtering runoff. Prior to the enhancements, a monoculture of primrose willow dominated the entire perimeter of the pond.

The primary objective of this project was to demonstrate how stormwater ponds can be designed to enhance their aesthetic and wildlife habitat values while at the same time meeting their intended water quality treatment and/or flood control purposes. The secondary objective was to actually improve the treatment effectiveness of the existing pond by expanding and planting the pond's littoral zone, increasing the treatment volume between the control elevation and overflow weir, and increasing the permanent pool volume, thereby increasing the residence time in the pond.

Educational Component: Due to the adjacent location of the County's Cooperative Extension Service, the project is readily available for touring by anyone visiting the Extension Service. Educational display boxes at various locations along the mulched path surrounding the pond provide information regarding the importance and function of stormwater treatment facilities. Also, as part of the project, the Extension Service produced a 28 minute educational video entitled “Stormwater Ponds: The new Urban Wetlands.” While the video discusses the importance of treating stormwater, it focuses primarily on the potential value of stormwater ponds for providing improved urban wildlife habitat. The video is used to inform groups such as homeowner associations, condominium associations, and civic associations, about stormwater pollution and management.

Project Cost: Total cost was $78,500, with construction costing $63,244. Funding was provided by a Section 319 NPS Grant from DER, the SWFWMD SWIM Program, and Pinellas County.

Project Evaluation: By more than doubling the permanent pool volume of the pond, the pond's residence time was substantially increased. The pond's treatment volume also was increased by 13.4%, from 0.50 inches of runoff to 0.57 inches. The increased residence time allows for longer periods of physical settling as well as biological activity. The reshaping and replanting of the littoral shelf resulted in increased nutrient uptake.

Urban Stormwater Retrofitting Project Fact Sheet

Jungle Lake Water Quality and Habitat Enhancement
Southwest Florida Water Management District

Watershed Area: 1000 acres

Watershed Land Use:

Project Overview: Walter Fuller Park is a highly used recreational/athletic park located in the western part of the city of St. Petersburg, approximately 2.5 miles east of Boca Ciega Bay. Jungle Lake was excavated about 75 years ago to provide fill for the construction of local roads. The 11.2 acre kidney-shaped lake received untreated stormwater from five inflows and discharges to the bay via a single outflow. During most storms, runoff bypassed Jungle Lake and was discharged directly to the bay. To improve the quality of water in the lake and that which is discharged to the bay, a BMP treatment train was constructed. The system includes:

- A diversion weir so that most stormwater is routed into the lake for treatment instead of directly into the bay.
- Modification of the inflow ditches to create shallow sloughs vegetated with native aquatic macrophytes.
- Expansion of the lake to create littoral zones vegetated with macrophytes.
- Two partially submerged berms which produce a longer flow path, increase residence time, provide natural habitat, and replace park uplands resulting from the lake perimeter modifications.
- Sediment sumps at the northeastern and southeastern inflows.
- An oil and grease skimmer on the outfall structure.
- Over 15,000 herbaceous plants consisting of 11 species, 170 trees, and 700 shrubs.

Project Cost: $328,000, which included $59,000 from the City of St. Petersburg and $269,000 from the SWFWMD SWIM Program. About 51,000 cubic yards of fill were needed for the project, of which over half would need to be imported at a cost of $3.80 to $4.75 a cubic yard. Since the area northeast of the lake was three feet higher than the surrounding roads and fields, this area was excavated instead. Within this area, two soccer fields were designed and constructed to provide the community with additional recreational facilities and to promote park usage. Even after the sodding of the soccer fields and the installation of an irrigation system, over $35,000 was saved.

Educational Component: During the conceptual planning and design phases, the City and SWIM staff met with members of the Jungle Lake Civic Association to obtain their input and to extend their ownership of the park to include the stormwater improvements. The members assisted in the selection of plants and received a grant to supplement the wetland and forest plantings. They also assisted in planting the vegetation and are participating in the educational, maintenance, and monitoring aspects of the project. The site has on display eight educational displays that inform the general public and students about stormwater issues and management. A teacher's manual was produced that can be used in the classroom or to accompany the signs during school field trips.

Urban Stormwater Retrofitting Project Fact Sheet

Oleander Avenue Stormwater Exfiltration Trench System
City of Daytona Beach, Florida

Watershed Area: 49 acres

Watershed Land Use: Single Family Residential -
23% Directly Connected Impervious Area (DCIA)

Project Overview: The Oleander Avenue watershed historically discharged untreated runoff to storm sewers that ultimately discharged to the Halifax River. The area was also subject to periodic local flooding due to the inadequate capacity of the conveyances. The primary objective of this project is to demonstrate the cost-effectiveness of using exfiltration systems as a method of retrofitting stormwater problem areas for future use within the city's beachside community.

To alleviate the flooding problem and to reduce pollutant loading to the river, a perforated pipe exfiltration trench treatment system was constructed. Site constraints limited the treatment volume to 0.75 inches over the DCIA which translates into a storage volume of 30,700 cubic feet. The 294 feet of exfiltration system is designed to accept the runoff from a 5 year, 24 hour storm representing flows of from 1.5 to 17.5 cfs from the drainage area subbasins. Actual pipe sizes varied from 19" x 30" to 29" x 45" to meet the design storm flow conditions. The rock filled trench measures 16 feet in width and 2 feet in depth.

Project Cost: Total cost was $513,700 with construction costing $375,617. This represents a cost of approximately $10,200 per acre. Funding was provided by DEP from a State Stormwater Demonstration Grant and from the City of Daytona Beach.

Project Evaluation: The exfiltration trench appears to be functioning very well as water quality monitoring efforts have failed to find any discharge from the system. Since exfiltration systems provide 100% treatment for all water which is retained and exfiltated, this system will reduce the stormwater pollutant loadings discharged to surface waters by at least 80%, since the trenches will eliminate the discharge from over 80% of the storms that occur. The project allowed the city to identify the design and construction constraints associated with this type of treatment system as well as installation costs for these systems. This knowledge will be used as the city retrofits other basins.

Urban Stormwater Retrofitting Project Fact Sheet

Indian River Lagoon Baffle Boxes
Brevard County Surface Water Management

Project Overview: The Indian River Lagoon National Estuary Program identified stormwater discharges as the major factor in the decline in the lagoon's health. In particular, reductions in the stormwater loadings of total suspended solids, nutrients, and freshwater are needed to restore the lagoon. The county developed an innovative BMP, the baffle box, which can be installed within existing rights-of-way as a way of retrofitting stormwater discharges where land is unavailable for traditional BMPs. Baffle boxes are large sediment traps that require regular maintenance. Sediment accumulation rates vary depending on site characteristics such as drainage area, land use, soil type, slope, mowing frequency, and base flow. The boxes accumulate from 500 to 50,000 pounds per month, and requires monthly cleaning in the wet season and cleaning every two to three months in the dry season. By the end of 1997, the county had installed 31 baffle boxes, with others under construction. As part of the implementation of the Indialantic area stormwater master plan, 11 baffle boxes currently are being installed and monitored. Three different designs are being evaluated to determine their effectiveness including: (1) a two-chamber box for small pipes and drainage areas; (2) a three-chamber box for larger pipes; and (3) two boxes in series, where one box currently exists and collects large amounts of sediment.

Project Drainage Area and Cost: The average cost of installing a baffle box is around $22,000 and the average clean out cost is $450 (by private contractor). Funding from a Section 319 NPS Grant from DEP and from the County's stormwater utility are paying for the Indialantic projects. These all serve mainly residential land uses. The construction costs and watershed drainage area are summarized below:

Project	Drainage area	Cost	Project	Drainage area	Cost
Alamanda	1.8 acres	$14,376	Franklin (2)	36 acres	$33,362
Rivershore	7.2 acres	$9,463	Riverside	161 acres	$24,944
Indialantic I	25 acres	$13,580	Sunset Part	24 acres	$23,422
Monaco	54 acres	$32,835	Puesta Del	2.2 acres	$25,181
Pinetree	134 acres	$33,925	Cedar Lane	0.9 acres	$25,027

Project Evaluation: The monitoring program for the 11 new baffle boxes will not begin until the spring of 1998. However, previous assessments of the effectiveness of baffle boxes on 22 existing systems is shown below:

The county has also installed a continuous deflective separation unit, a new BMP from CDS Technologies of Australia. This unit cost $55,000 to install and treats the runoff from a 40 acre watershed. This unit captures 100% of floatables and has been cleaned out twice resulting in the removal of 8,013 pounds of sediment.

Urban Stormwater Retrofitting Project Fact Sheet

Oil and Grease Removal BMP Demonstration
City of Oakland Park, Florida

Watershed Area: 5 acres

Watershed Land Use: Mixed commercial and industrial (95% Impervious)

Project Overview: The City of Oakland Park received one of the state's Stormwater Demonstration Grants to develop and monitor a prototype BMP for in-line removal of oil and grease from stormwater using oil absorbent material. The Northeast 40th Court site was chosen because inspection of the storm sewer system revealed substantial amounts of oil and grease. These were attributed to the large number of automobile repair shops, paint shops, plating shops, and similar businesses in the drainage area. The project consisted of characterizing the concentrations of oil and grease in the stormwater, a review of the material safety data sheets of three different oil sorbent materials, a laboratory bench scale study of one of the oil sorbent materials, construction of the BMP system, and effectiveness monitoring. The final BMP system included diversion box with a weir to direct runoff into the treatment system. As stormwater enters the treatment unit, flow is directed against an aluminum baffle imparting a slight rolling motion which causes floatables and trash to be trapped against the baffle wall for easy removal. Upon entering the treatment chamber, velocity slows greatly, allowing grit, sludge, and oil particulate matter to settle to the sloping bottom. The stormwater is then redirected upward through two cross-layers of the absorbent media, which are secured by being sandwiched between two aluminum grates, where free oil and grease are removed via absorption into the material. The absorbent media chosen was custom made by NewPig Corporation of Tipton, Pennsylvania. The product, called the Spaghetti Pillow, consists of shredded strips of polypropylene packaged in tough, UV resistant mesh skin in the shape of a rectangular bag or pillow. The two layers of media are placed perpendicular to each other to avoid short circuiting.

Project Cost: Total cost of the project was $260,870. This included $71,490 for the construction of the treatment system and $189,380 for sampling equipment, consultant, and laboratory fees.

Project Evaluation: Inflow and outflow sampling of the system was conducted for ten storms between July 1994, and April 1995. Storm event oil and grease concentrations ranged from 0 to 261 mg/l, with mean pollutant concentrations ranging from 1.41 to 85.58 mg/l. Oil and grease mass removal efficiencies ranged from 71% to 95%, while flows ranged from 0 to 1.75 cfs. The absorbtion efficiency of the filter media bags were measured twice. The amount of oil and grease absorbed ranged from 1.7 pounds to 62.5 pounds, which represents an absorbtion efficiency of 110% to 470%.

Urban Stormwater Retrofitting Project Fact Sheet

BMP Treatment Train in the Florida Keys
City of Key Colony Beach, Florida

Watershed Area: 268 acres

Watershed Land Use:

Project Overview: Recognizing the importance of reducing stormwater pollution in protecting its sensitive natural resources, the City included in its comprehensive plan policies requiring the retrofitting of its existing drainage system. With technical assistance from the DEP and the SFWMD, the City's consultant developed a stormwater master plan in 1993. The plan included plugging 28 existing stormwater outfalls and constructing a retention basin and swales with raised inlets and exfiltration trenches which overflow into injection wells. Implementation of the master plan began in 1995, and is scheduled for completion by the year 2000. Phase 1 has been completed and Phase 2 will be completed by the fall of 1998. The stormwater master plan calls for the construction of 82,146 linear feet of swales, 9 modified raised swale inlets, about 60,000 linear feet of exfiltration trench, 35 inlet baffle systems to direct the first flush into the exfiltration trenches, and 22 injection wells.

Project Cost: The total cost of the original stormwater retrofitting master plan was estimated to be $1.2 million. However, the city's residents and elected officials decided that they did not want water standing in the swales, resulting in the addition of the exfiltration trench system. To date, using funds from the city, the DEP, and a Section 319 Grant, the city has implemented two phases of the master plan as shown below:

Basin	Acres	Swale (lf)	Sod (sF)	Exf. Trench (lf)	Injection Wells	Cost
4-1	0.66	827	29,257	445	1	$72,200
5-2	3.03	521	21,304	269	0	$47,083
2-2	3.50	1200	14,000	1200	1	$148,112
2-5	3.00	1200	14,000	1200	1	$147,790
2-8	2.13	934	11,000	934	1	$129,600
2-11	1.76	566			1	$27,854
3-1	3.69	878	11,000	878	1	$113,175
5-1	26.47	4800	37,000	3100	3	$439,773
8-2	0.02	1306	371	371	1	$72,174

Project Evaluation: Actual stormwater monitoring will not begin until the completion of Phase 2. By plugging the direct stormwater discharges to surface waters and providing storage and treatment for the first 1.5 inches of runoff, the stormwater volume and pollutant loadings will be substantially reduced. Modeling indicates that these will be reduced by up to 75% from pre-project conditions.

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Evaluating the Cost Effectiveness of Retrofitting an Urban Flood Control Detention Basin for Stormwater Treatment

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This paper describes the retrofitting of a flood control basin in Sunnyvale, California and subsequent monitoring to evaluate the pollutant removal effectiveness of the retrofitted basin. The authors wish to thank the Santa Clara Valley Urban Runoff Pollution Prevention Program, and especially the City of Sunnyvale for their support and cooperation in the conduct of this study.

Background

The northern portion of Santa Clara Valley experienced significant subsidence during a period of excessive groundwater pumping. In order to protect that area from flooding, a system of levees and pump stations were built. According to a survey conducted in 1990, there are 17 municipally owned and operated pump stations in Santa Clara Valley (Woodward Clyde Consulting, 1990). These pump stations generally consist of pumps, storage units such as a sump or a detention basin, and inlet and outlet works. Sumps and detention basins are designed to reduce the capacity of the pumps that would otherwise be needed to pass peak flood flows. These pump stations have generally been operated as single-purpose flood control facilities. The pump operating schedules are designed such that the pumps go on as soon as water begins to fill the basin, with the goal of emptying the basin as soon as possible after the event. These facilities were examined for their potential to provide water quality treatment in addition to flood control. One retrofitting option to achieve water quality benefits would be to change the pump operating schedule in order to increase detention time and to provide for a seasonal wet pond. Based on a preliminary evaluation of the feasibility of retrofitting detention basins, the Santa Clara Valley Urban Runoff Pollution Prevention Program decided to conduct a pilot study to retrofit a facility, and conduct testing to measure water quality benefits and costs (Woodward Clyde Consulting, 1994).

Site Description

In this pilot study, structural and operational retrofitting was conducted on Sunnyvale Pump Station No. 2 located just north of the junction of Route 237 and Calabazas Creek. The pump station consists of four primary pumps rated at 39 cfs capacity and one auxiliary electric pump (9 cfs). The detention basin area is 4.4 acres with a 30-acre-ft capacity; it receives water from a 463-acre watershed that consists of industrial park (30%), commercial (10%), and residential (60%) land uses (Figure 1).

Retrofitting Actions

The basin, originally constructed as an in-line dry detention basin with pumped outflow, was retrofitted to operate as an in-line extended detention basin with a seasonal wet pool and pumped outflow. The retrofitting required one operational and three structural changes. The detention basin has an open channel and a submerged 36-inch pipe (which was below the open channel) that connected the inlet and outlet. In order to minimize short-circuiting, a single barrier of rock was placed in the channel and a riser was placed over the entrance to the 36-inch pipe. A gabion weir was installed at the outlet to provide better distribution of flow from the basin into the outlet.

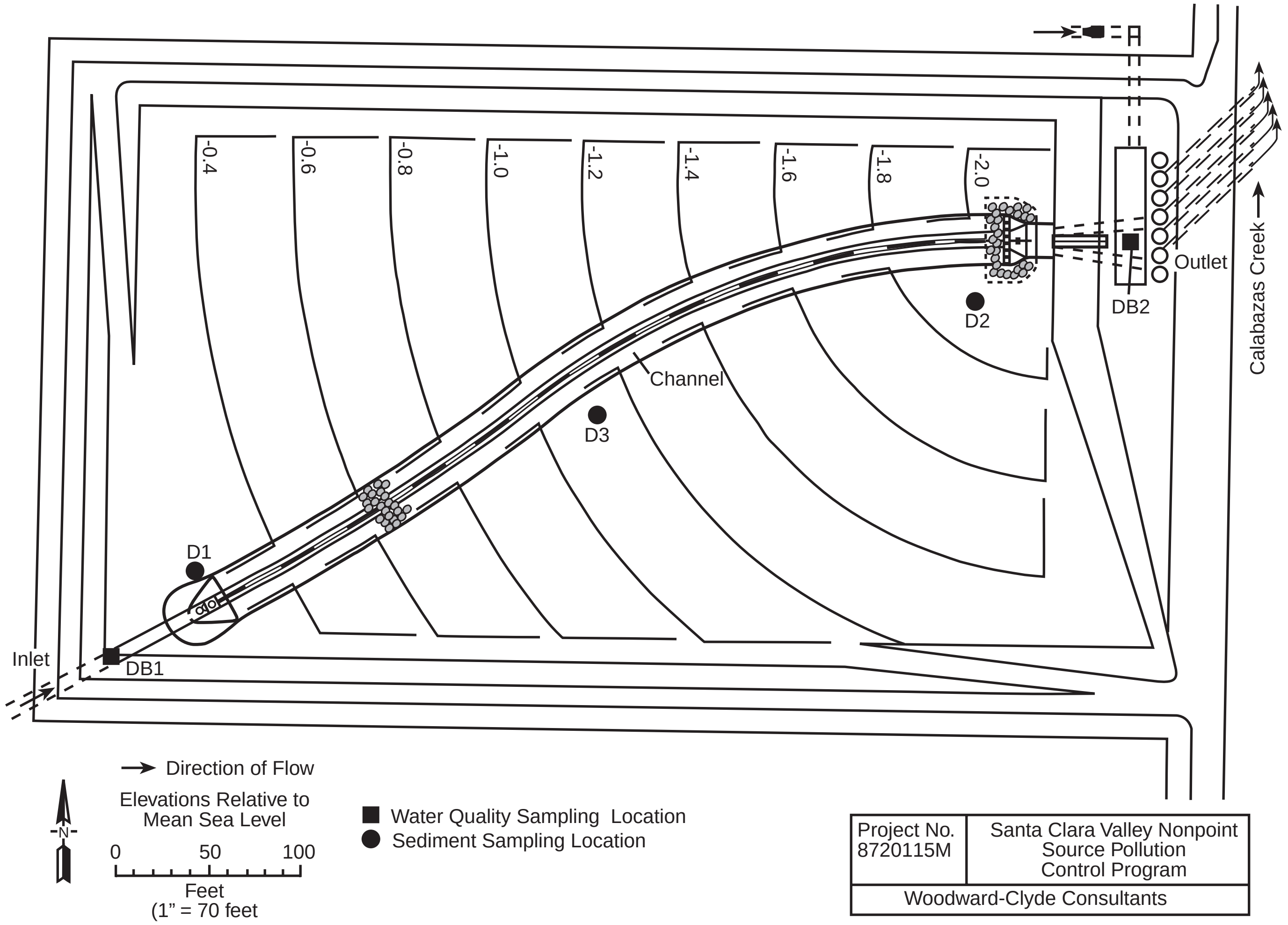

Figure 1. Sunnyvale Pump Station No. 2 showing sampling locations.

Operational changes consisted of modifying the pump schedule to create a 2-foot permanent pool at the outlet, provide a temporary pool over the depth range of 2 to 2.4 feet, and provide slow release for water depths above 2.4 feet. The 2.4-foot maximum for the temporary pool was estimated based on a flooding analysis to ensure that modifications to the pumping schedule did not cause a significant increase in the 100-year flood levels in the detention basin.

Monitoring

Flow data and water quality samples were obtained using automated samplers located in the pump station and in the pipe entering the basin. Flow-weighted composite samples were obtained from eight storm events over three wet seasons (October through April) between March 1991 and April 1993. Characteristics of the monitored storms are given in Table 1.

Water sampling was conducted for total suspended solids (TSS), selected heavy metals (total and dissolved cadmium, chromium, copper, lead, nickel, and zinc), and oil/grease. Table 2 shows how the metals concentrations at the inlet to the basin compare with data collected from other urban monitoring stations that sampled relatively single-land use catchments. Data from the detention basin inlet were most similar to residential/commercial data. Two rounds of sediment samples were also collected at three locations in the basin (near inlet, midway between inlet and outlet, and near outlet) to characterize sediment grainsizse and chemistry in the basin.

No data were obtained prior to retrofitting the facility to estimate "before and after" performance. However, based on the design and operation of the facility, pre-retrofit treatment performance was predicted to be quite low (Woodward Clyde Consulting, 1990).

Monitoring Results and Pollutant Removal Effectiveness

Because of difficulties in obtaining consistent and reliable flow measurements, pollutant removal effectiveness was estimated based on the difference between influent and effluent concentrations rather than loads (Table 3).

Table 1. Storm Sampling Event Statistics for the Detention Basin

Storms		Rain (San Jose NWS gauge #7821)				
Sampling Event	Date	Duration (hours)	Volume (in)	Average Intensity (in/hour)	Peak Intensity in/hour)	Antecedent Dry Period (days)
SE17	3/20/91	11	0.4	0.04	0.10	2
SE20	2/12/92	17	1.3	0.08	0.20	3
SE21b[1]	3/22/92	19	0.6	0.13	0.20	1.3
SE23	12/6/92	16	1.1	0.07	0.20	39
SE24	12/10/92	6	0.9	0.15	0.30	4
SE25	1/6/93	29	0.5	0.02	0.10	5
SE27	2/17/93	60	2.2	0.04	0.20	6
SE28	3/23/93	14	1.1	0.08	0.20	7

[1] Consists of two small storms.
Note: The median event volume for the period from 1948 to 1989 was 0.49 inches.

Table 2. Comparison of Median Total Metal Concentrations in Stormwater at the Detention Basin Inlet to other Santa Clara County Monitoring Stations

	Concentrations (μg/L)			
Parameter	Detention Basin Inlet Station n = 8	Residential - Commercial Land Use Stations (L1, L3, L4, L5, L6) n = 21	Industrial Land Use Station (L2) n = 25	Open Land Use Station (L7) n = 4
Cadmium	1.1	1.0	3.9	0.3
Chromium	11.5	16.0	24.0	10.5
Copper	24.0	33.0	50.5	11.0
Lead	37.5	45.0	90.5	2.0
Nickel	20.5	30.0	46.0	5.0
Zinc	180.0	240.0	1150.0	5.0

Average removal of TSS was 50%. Removal of total chromium averaged about 30%, removal of total copper and zinc was about 40%, and removal of total lead and total nickel averaged about 50%. The data indicated that the basin did not remove dissolved metals or hydrocarbons. Estimates for removal of total cadmium were not made because the concentrations in the influent and effluent were very low (at or near the laboratory detection limit).

Sediment samples were also collected at various locations within the basin (see Figure 1) were tested for selected heavy metals (Table 4). Sediment concentrations were higher near the inlet, but none of the samples contained metals at concentrations exceeding hazardous waste criteria. Estimated sediment accumulation rates were low, as expected for a fully urbanized area, with cleanout frequencies estimated at between once every 10 or 20 years.

Cost-Effectiveness Evaluation

The amortized cost over 20 years for retrofitting, operations and maintenance (including sediment disposal) was estimated at $8,200 per year. Based on this cost and assuming flow rates were typical, the cost effectiveness of removing the metals was estimated. For example we estimated that, 1.1 lb. of copper could be removed per $1,000 spent on retrofitting. This compares well with an estimate of 1.5 lb. of copper for $1,000 spent on street sweeping.

However, the potential for significantly reducing heavy metals loads to the Bay due to retrofitting the existing flood control facilities is minimal because only a small portion of the watershed is served by detention facilities. Even if the other existing flood control facilities were retrofitted, and achieved improved removals comparable to those measured in the pilot study, the net reduction in copper would only amount to approximately 100 pounds per year, which is less than 1% of the estimated mean annual copper load to the Bay (14,000 lb.).

Conclusions

- Flood control basins, especially those with pumped outlets, may be good candidates for retrofitting for water quality control without increasing flood control risk.
- Metal removals measured in the retrofitted basin ranged between about 30-50% depending on the metal and about 50% for TSS. The basin did not appear to be effective in removing oil/grease.
- Concentrations of metals in the sediments tended to be higher near the inlet, but were well below hazardous waste criteria.
- Amortized costs for retrofitting the basin were about $8,200/year, and based on the pollutant removal per-

Table 3. Summary of Inlet and Outlet Concentrations for Selected Pollutants at the Detention Basin

	Cadmium (µg/L)		Chromium (µg/L)		Copper (µg/L)		Lead (µg/L)		Nickel (µg/L)		Zinc (µg/L)		TSS	TH	TO&G
	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	(mg/L)	(mg/L)	(mg/L)
SE17															
B1 - Inlet	0.4	<0.2	3.6	1.8	8.7	5.4	6.4	2.2	1.7	<2	46	28	12	97	1.5
B2 - Outlet	0.2	<0.2	2.7	1.1	6.8	4.7	3.4	1	1.7	<2	26	19	7.3	120	1.4
Reduction	-	-	25%	-	22%	-	47%	-	0%*	-	43%	-	39%	-	7%
SE20															
B1 - Inlet	6.6	1.3	12	1	24	3	45	1	16	1	180	19	90	110	0.2
B2 - Outlet	4.8	2.5	6	1	9	3	10	1	4	1	73	22	24	63	<0.2
Reduction	-	-	50%	0	63%	-	78%	-	75%	-	59%	-	73%	-	-
SE21b															
B1 - Inlet	1.1	0.2	18	1	24	2	53	<1	25	<1	180	5	140	-	-
B2 - Outlet	1.5	<0.2	14	1	16	2	35	<1	19	<1	120	7	93	-	-
Reduction	-*	-	22%	-	33%	-	34%	-	24%	-	33%	-	34%	-	-
SE23															
B1 - Inlet	1	0.2	11	<1	27	5	30	1	13	3.9	190	41	74	100	0.7
B2 - Outlet	0.6	<0.2	8.3	1.4	12	4.7	12	<1	5.8	2.2	82	45	31	90	0.5
Reduction	-	-	25%	-	56%	-	60%	-	55%	-	57%	-	58%	-	-
SE24															
B1 - Inlet	1.6	<0.2	21	1.1	40	2.1	76	<1	42	9.6	270	22	180	140	0.6
B2 - Outlet	1.3	0.2	15	8.6	24	5	40	1.4	29	15	160	31	96	140	3.5
Reduction	-	-	29%	-	40%	-	47%	-	31%	-	41%	-	47%	-	-
SE27															
B1 - Inlet	1	0.5	6.3	1.4	14	5.4	13	<1	83	63	70	35	30	110	1.6
B2 - Outlet	0.6	0.4	4.9	1.7	8.9	4.5	6.6	<1	25	20	47	26	15	220	1.3
Reduction	-	-	22%	-	36%	-	49%	-	70%	-	33%	-	50%	-	-
Average															
Reduction	-	-	29%	-	42%	-	53%	-	51%	-	44%	-	50%	-	-

Table 4. Sediment Grain Size and Chemistry for the Detention Basin

Station	Date	Type of	Grainsize %			%	%	Metals Concentrations (mg/kg)						
Location	Sampled	Sample	Sand	Silt	Clay	Solids	TOC	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel
Composite†	6/15/90	3" Core	-	-	-	-	-	2.2	-	92	-	36	-	61
D1 Inlet	5/14/92	Surficial	0	75.3	24.7	32	3.8	23	200	150	49,000	280	610	94
D3 Middle	5/14/92	Surficial	0	85.4	14.6	31	5.5	17	220	140	38,600	350	640	87
D2 Outlet	5/14/92	Surficial	0	72.4	27.6	34	1.9	35	140	47	47,700	18	680	76
D1 Inlet	7/12/93	Surficial	-	-	-	53	2.4	1.0	170	110	34,000	260	560	96
D3 Middle	7/12/93	Surficial	-	-	-	63	0.65	0.2	120	37	36,000	12	700	75
D2 Outlet	7/12/93	Surficial	-	-	-	63	0.93	0.3	110	43	30,000	24	570	73
Total Threshold Limit Concentration*								100	2500	2500	-	1000	-	2000

† Core samples were taken at station D1, D2, and D3, and composited for one analysis.
* Title 22 of the California Code of Regulations.

formance, yielded cost-effectiveness values that were somewhat comparable to street sweeping.

- Because of the limited number of basins and the small portion of the watershed served by those basins, basin retrofitting would reduce watershed loads of metals by only about 1%.

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Retrofitting to Protect Drinking Water Reservoirs from the Impacts of Urban Runoff

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To meet federal Surface Water Treatment Rule (SWTR) requirements and Filtration Avoidance mandates, the New York City Department of Environmental Protection has developed a proactive program to manage and protect the Kensico Reservoir and its watershed. The prime components of the program are aggressive stormwater and waterfowl management, sewer system inspection and repair, an in-reservoir turbidity curtain, reservoir dredging, and hazardous spill containment. Protecting water quality in the Kensico Reservoir is imperative because it is the final impoundment for 90% of the city's unfiltered water supply before it enters the distribution system. This paper focuses on the stormwater management element, which targets pathogens and turbidity, the key pollutants regulated by the SWTR that are conveyed to the reservoir by stormwater. The first phase of the project, watershed assessment, site selection, and stormwater management facility screening and design, is complete. Lessons learned and recommendations for planning similar efforts are summarized in this paper. Construction of the stormwater facilities is scheduled to begin in the spring of 1998 and to be completed in two phases, over a five-year period. Baseline stormwater water quality data will be collected until the facilities are constructed. Data will be collected from select stormwater facilities once they are operational in order to assess the effectiveness of the program.

Introduction

New York City has placed great emphasis on protecting and improving the quality of its drinking water supply through watershed protection and management programs. This paper describes one such program developed and implemented by the New York City Department of Environmental Protection's (NYCDEP) Bureau of Water Supply, Quality and Protection.

The city's drinking water supply system is one of the largest in the world, supplying 1.45 billion gallons of water each day to 9 million city and upstate residents. The entire watershed covers 1,969 square miles and comprises 19 reservoirs and three controlled lakes (lakes in which the city has water ownership), and numerous wetlands watercourses and intermittent streams. Land use, topography, hydrology and political climates vary dramatically within and among the system's three watersheds: the Delaware, the Catskill and the Croton (Figure 1). One reservoir, the Kensico, is integral to managing the unfiltered Catskill and Delaware systems because it serves as the final impoundment for Catskill and Delaware water before it enters the distribution system. On average, approximately 1.3 billion gallons flow through the Kensico Reservoir each day. This accounts for 90% of the system's daily demand. For this reason, it is important to control the quality of stormwater entering the reservoir from developed land.

The U.S. Environmental Protection Agency recognizes the importance of the Kensico Reservoir and has required the NYCDEP to implement a watershed management and protection plan that targets fecal coliform bacteria and turbidity. Plan elements include aggressive stormwater and waterfowl management programs, sewer system inspection and repair, an in-reservoir turbidity curtain, and hazardous spill containment. This paper focuses solely on the stormwater management element which includes hazardous spill containment. Brief descriptions of the other components follow.

Sewer Inspection and Repair

The sewer system within the watershed, including type and size of pipe and manhole locations, was mapped. Of the 95,000 feet of sewer line in the watershed, 55,000 feet were installed before 1970 and are more prone to defects. The older sections of sewer line were inspected for potential sources of exfiltration, and cross or illicit connections. No illicit connections were discovered; 39 segments and three manholes were found to be in need of repair. The town of Mount Pleasant and Westchester County are completing the repairs under intermunicipal agreements.

Waterfowl Management

The waterfowl management program is designed to eliminate or reduce the numbers of geese and gulls roosting and defecating in or near the surface water through hazing, using noisemakers, motorboats, hovercraft, and bird distress tapes; shoreline meadow management and physical barriers; and Canada geese egg depredation. The program, implemented August 1 through March 31, also in-

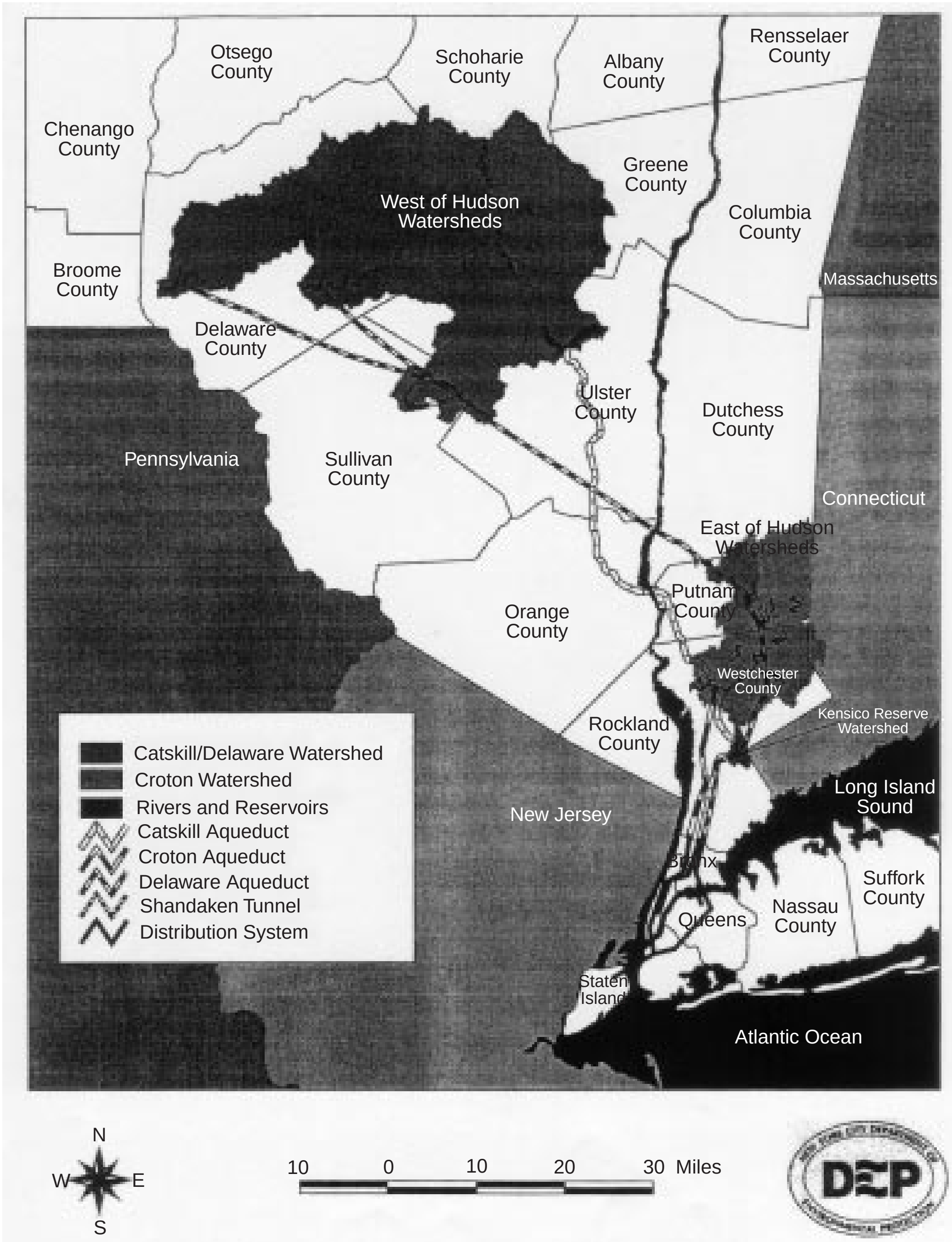

Figure 1. New York City's water supply system.

cludes research into new methods of bird control and ongoing assessments of program effectiveness. Although labor intensive, the waterfowl management program is a permanent program because it eliminates the greatest source of fecal coliform bacteria.

Turbidity Curtain

The turbidity curtain (like a silt fence 750 feet long with floats on top and weights on the bottom) installed at the mouth of Malcolm Brook in the southwest section of the Kensico Reservoir successfully directs turbidity and fecal coliform bacteria conveyed to the reservoir away from the Catskill Upper Effluent Chamber. Maintaining high-quality water in the effluent chamber is critical as water is conveyed directly to the distribution system from the chamber. Water entering the chamber is constantly monitored to determine compliance with the SWTR. Since the curtain has been so effective, it is a permanent program.

Reservoir Dredging

The channels leading to the reservoir's two effluent chambers, and the sediment deltas at the mouths of Malcolm and Young Brooks will be dredged in 1998. Dredging will eliminate the potential for accumulated sediments to be resuspended during storms, potentially causing a contravention of turbidity and fecal coliform bacteria water quality standards.

The Kensico Reservoir Stormwater Management Project is designed to reduce fecal coliform bacteria and turbidity delivered to the reservoir by controlling and treating stormwater. As turbidity is a direct measure of suspended solids in the water column, the stormwater component targets sources of suspended solids. The first phases of the project, assessment of the watershed, site selection, and the screening and design of stormwater control and treatment facilities, were completed in December 1997. Funding is in place to construct the stormwater facilities over a 5-year period, beginning in March 1998. The NYCDEP has committed to maintaining, monitoring, and evaluating the performance of the facilities.

Phase I: Watershed Assessment

The Kensico Reservoir watershed occupies approximately 13 square miles and includes four suburban towns in Westchester County, New York, plus a small portion in Fairfield County, Connecticut (Figure 2). To assess stormwater pollutant loading in the Kensico watershed, the reservoir basin's physical characteristics, including land use, soils, topography, vegetation and reservoir tributaries, were inventoried and digitally mapped. The watershed's topography is hilly and rolling, and over two-thirds of it contains slopes greater than 8%. Almost one-third of the land area is used as passive open space, and approximately one-fifth of the land area is developed with low-density residential uses (Figure 2). The remaining land area is primarily active open space, farmland and commercial/business. As water quality is, in part, a function of the amount of impervious surfaces in the watershed, of greatest concern is developed land directly adjacent to the effluent chambers that convey drinking water to the consumers.

Phase II: Stormwater Remediation Needs Assessment and Management Plan Development

A preliminary assessment of stormwater remediation needs in the Kensico watershed was conducted by evaluating tributary water quality data, land use/impervious surfaces, SWMM model predictions of runoff quantity and quality, and field observations of existing erosion. That evaluation concluded that 73 of the watershed's 148 sub-basins have a relatively high potential to contribute fecal coliform bacteria and suspended solids to the reservoir. Using the criteria listed below, reservoir tributaries in 19 of the 73 sub-basins were prioritized for stormwater remediation.

Preliminary Stormwater Remediation Evaluation Criteria

- proximity to reservoir effluent chambers
- known or potential sources of pollutants
- quality and quantity of stormwater runoff
- presence of wetlands
- topography
- property ownership
- observed erosion

Based upon these criteria, conceptual designs were prepared for 88 stormwater management facilities and erosion controls within 19 sub-basins. The conceptual designs were the basis for an environmental evaluation and impact statement.

The conceptual stormwater management plan was then refined by applying the selection criteria (bulleted below) in combination with the results of detailed field investigations, maintenance requirements and site constraints. A total of 57 stormwater management facilities were sited to reduce erosion, manage peak stormwater flows, allow for settling of sediments and coliform die-off, and ultimately reduce pollutant loads delivered to the reservoir (Figure 3). During the process of developing preliminary facility designs, property owners required that five facilities be redesigned, and denied permission to construct the facilities at three sites. Ultimately, 44 engineered designs were finalized. Facility types included 10 extended detention basins, 14 segments of stream channel stabilization, 13 stabilized outlets, one area of parking lot stabilization, and one sand filter system. Road stabilization and drainage improvements were incorporated into stilling and detention basins and sand filter designs. Hazardous spill containment is being addressed in coordination with a major road improvement project that will significantly alter drainage along the Interstate 684 and Route 120 corridors which abut the reservoir. The conceptual plan includes four extended detention basins that will serve as spill containment facilities, and containment booms to be deployed at the 22 storm drain outlets along I-684 in the event of a spill.

Site Selection and Conceptual Facilities Evaluation Criteria

- Do the site and the facility meet the intent of reducing pollutant loads?
- Does the facility minimize impact to environmental resources and achieve measurable water quality benefits?
- Does the existing condition warrant engineered improvements?
- Are there property ownership/permission constraints which make implementation impractical or impossible?
- Have any watershed/land use conditions or assumptions changed since issuance of the Final Environmental Impact Statement which affect the appropriateness of the facility and/or the site?
- Are there likely to be permit issues which will compromise the viability of the practice?

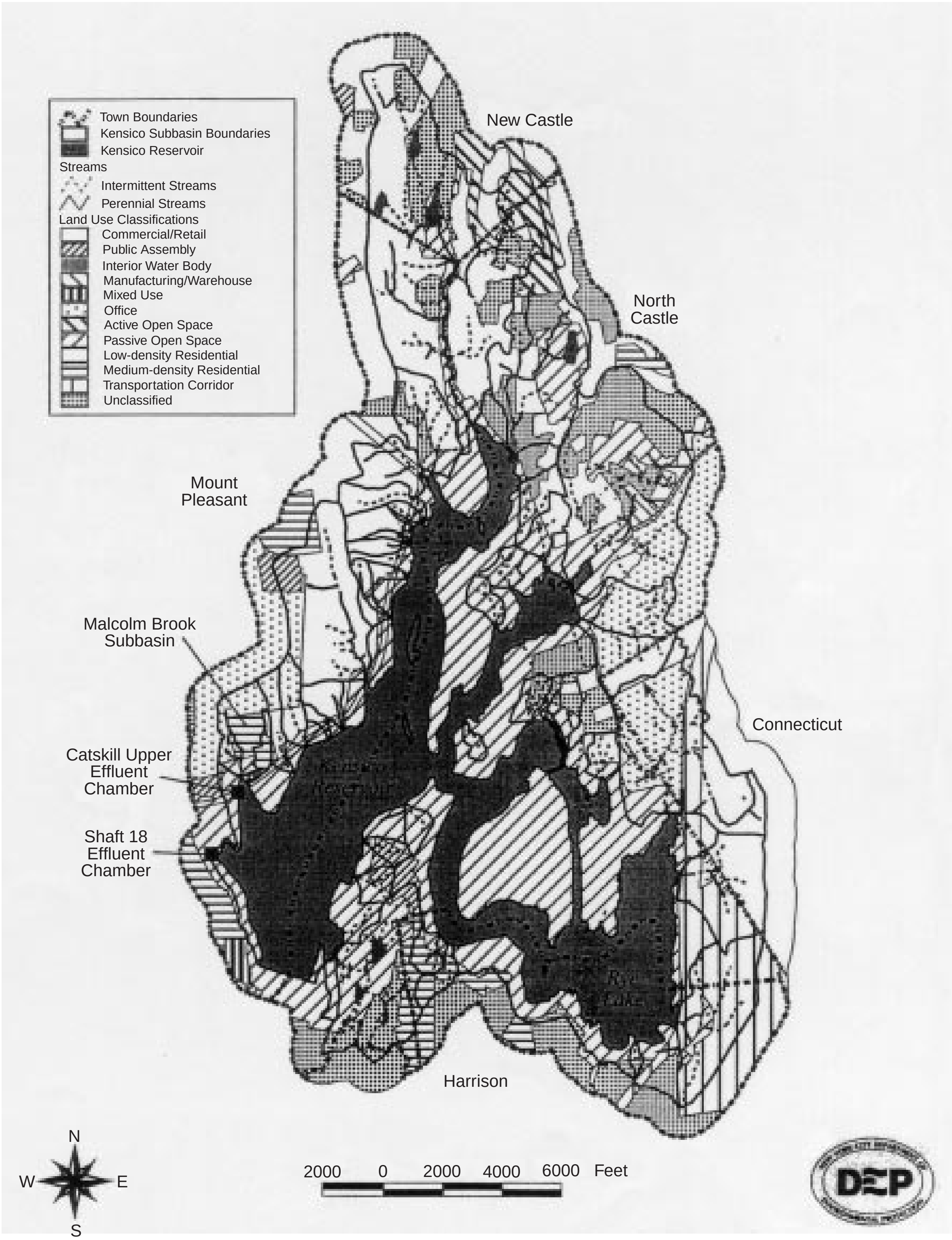

Figure 2. Land use in the Kensico Reservoir Watershed.

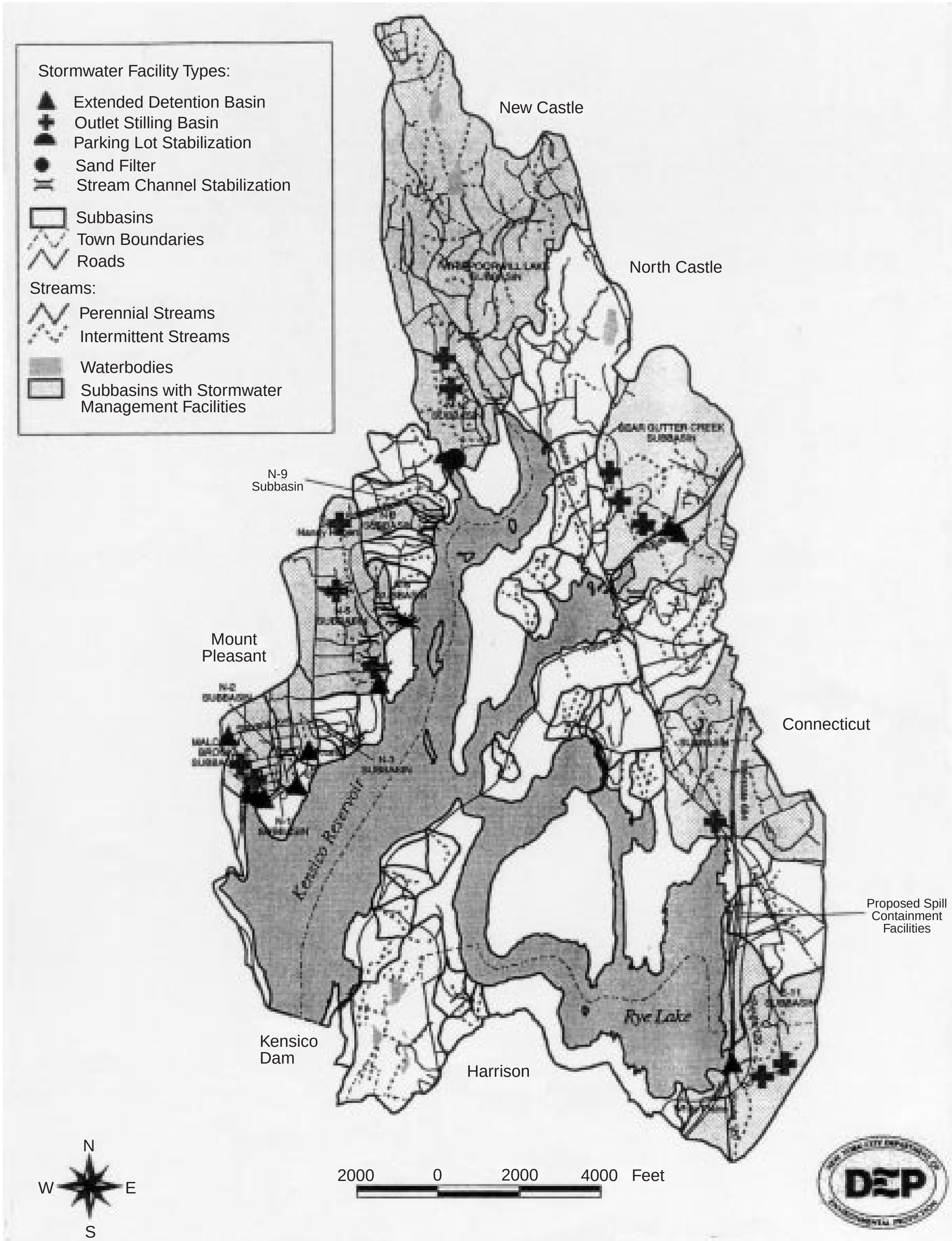

Figure 3. Proposed stormwater management facility sites in the Kensico Reservoir watershed.

- Are the maintenance and/or operation requirements of the practice, so burdensome as to effectively make the practice inappropriate?

Having met the final screening criteria, each facility was designed to minimize on-site and downstream impacts without sacrificing water quality benefits. For example, the designs incorporated existing topography, avoided wetland encroachment, and incorporated emergent wetland features necessary for long-term maintenance and features to discourage waterfowl attraction. The attention given to minimizing disturbances and subsequent on- and off-site impacts was a crucial component of enlisting the support of the community, regulatory agencies and private property owners.

Phase III: Implementing the Stormwater Management Plan in a Developed Area

Generating Community Support

The final plan proposes to construct 44 stormwater management facilities and erosion controls on public and private property. Immediately after proposing the 88 conceptual facilities, NYCDEP identified the property owners, and launched an outreach campaign to explain and generate support for the project. The ultimate goal of the campaign was to secure legal permission to gain access to design, construct, and maintain the facilities on private property. Securing permission to construct 18 facilities on private land holdings from 32 land owners has been a challenging aspect of the project. Alternate sites in the same sub-basin were pursued where access to private property was denied during preliminary design development.

Obtaining Regulatory Approvals

An expert advisory panel was enlisted to review conceptual plans and facility designs for the highest priority sub-basin, Malcolm Brook, which discharges in the immediate proximity of the Catskill Upper Effluent Chamber. Panel members were volunteers from academia and government agencies that are actively involved in planning and implementing stormwater management projects. The panel's comments helped shape the plans and designs, and were used to support certain aspects of the plan when applying for regulatory approvals.

Municipal support for the project and regulatory approval to construct the facilities were also needed. Initially, this involved a series of explanatory meetings with the town supervisors, engineers and planners. Once support for the conceptual project was obtained, the standard applications for local permits and approvals were submitted. A similar process of "pre-application" meetings was followed with federal and state permitting agencies. The pre-application meetings set the stage for the relationship between NYCDEP, the municipalities and regulatory agencies, and allowed the agencies to comment on the designs before they were finalized and permit applications were submitted. The goal of the pre-application process was to minimize the need for design revisions and to avoid delays during the regulatory approval process.

Modeling Water Quality Benefits

Water quality modeling predictions can provide valuable supporting information when developing stormwater management plans, if sufficient data are available. The U.S. Environmental Protection Agency's Stormwater Management Model (SWMM) was used to simulate runoff volumes and turbidity and fecal coliform bacteria loading in select tributary sub-basins of the Kensico Reservoir. The model predicted pollutant loads under existing conditions and future build-out conditions in the year 2010, with and without the project. With the projected increase in impervious surfaces, results from modeling estimated that future stormwater loads of turbidity and fecal coliform bacteria inputs to the reservoir will increase by 16% and 21%, respectively. Model predictions also estimated that construction and operation of stormwater facilities will reduce future inputs of turbidity and fecal coliform bacteria by 23% and 15%, respectively, when compared to future loads without the stormwater controls. The overall effect of the program on reservoir water quality will be less than the benefit associated with the targeted tributaries. Thus, for example, the model predicts much higher reductions in turbidity at the discharge of Malcolm Brook, than for the reservoir as a whole, 95% and 9.9%, respectively. Model predictions of anticipated water quality benefits in individual basins are listed in Table 1. In addition to the predicted reductions, the extended detention basins will attenuate peak rates of stormwater discharge and reduce peak concentrations of pollutants delivered to the reservoir. The results predict that the plan will have substantial water quality benefits.

Constructing, Operating, Maintaining and Monitoring Facilities

NYCDEP recognizes the need for an aggressive maintenance program to ensure that the stormwater facilities function as originally designed. Prior to construction, inspection and maintenance plans and contracts to carry out the plans will be in place. Further, water quality monitoring stations have been incorporated into facility designs and studies have been designed that will evaluate the performance of the stormwater controls.

The stormwater plan will be implemented sub-basin by sub-basin, with construction scheduled to begin in the spring of 1998. The construction schedule was prioritized using criteria that included severity of erosion, water quality benefits, proximity to the effluent chambers, and permitting and property owner constraints.

Conclusions, Recommendations and Challenges

The Kensico Reservoir watershed stormwater management plan will improve water quality in the reservoir by controlling and treating stormwater runoff in select tributaries. An aggressive public outreach campaign, designing the facilities to minimize site and resource disturbances, and providing for proper maintenance of stormwater controls and monitoring effectiveness, were high priorities for

Table 1. SWMM Model Predictions of Tributary Loads of Turbidity and Fecal Coliform Bacteria

	Future Load without Plan		Future Load with the Plan	
Tributary Sub-basin	Turbidity	Fecal Coliform Bacteria	Turbidity	Fecal Coliform Bacteria
Malcolm Brook	5% increase	6% increase	95% reduction	72% reduction
N1	104% increase	95% increase	91% reduction	60% reduction
N2	9% increase	11% increase	81% reduction	41% reduction
N3	14% increase	10% increase	63% reduction	38% reduction
N4	103% increase	106% increase	90% reduction	52% reduction
N5	30% increase	23% increase	84% reduction	54% reduction
N12	107% increase	not modeled	68% reduction	not applicable
Bear Gutter Creek 5	60% increase	59% increase	77% reduction	59% reduction
Bear Gutter Creek 8	76% increase	73% increase	95% reduction	64% reduction
Whippoorwill	11% increase	not modeled	11% increase	not applicable
E11	0% increase	0% change	96% reduction	70% reduction

NYCDEP. The stormwater management plan will be used as a template for similar efforts in other urban reservoir watersheds, and in NYCDEP's overall stormwater management, mitigation, and cost-sharing programs. Program recommendations are as follows:

- An aggressive outreach campaign is needed to secure support for the project, get permission to include privately-owned land in the retrofit program, and obtain regulatory permits and approvals. The campaign should begin during conceptual plan development and continue through facility construction and operation.
- The pre-application review process can streamline the permitting and approval process.
- Water quality modeling results can support the selection and prioritization of sites and facility types.
- The inspection and maintenance requirements should be defined and commitments to carry out the requirements should be obtained prior to construction.
- The advisory panel formed to review conceptual plans and facility designs should be fully informed of watershed conditions, jurisdictional constraints and agency capabilities.
- Design and construction contract bid documents and payment processes should be clearly defined such that all parties itemize work units in the same manner.
- A contractor should be selected that is experienced in watershed assessment, as well as application of the remediation programs likely to be warranted in the area.
- Facility designs should maximize water quality benefits and minimize disturbances to natural resources. Water quality monitoring capabilities should be included in facility designs.

Acknowledgments

Roy F. Weston, Inc. of New York (Valhalla, NY) was contracted to develop the Kensico Water Quality Control Program and conceptual stormwater management plan.

Hazen and Sawyer, P.C. (Manhattan, NY) was contracted to reevaluate the conceptual stormwater management plan, prepare engineering designs and construction cost estimates for stormwater management and erosion control in the Kensico Reservoir Watershed, and prescribe inspection and maintenance requirements.

Empirical Modeling Approaches for Establishing Nutrient Loading Goals for Tampa Bay

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The Tampa Bay National Estuary Program (TBNEP) has guided and supported the development of an empirically based approach to setting external nitrogen load targets for Tampa Bay, FL. Working closely with the scientists and resource managers of the TBNEP, the authors used the available data to elucidate relationships among loadings, water quality, and the subsurface light environments. These relationships were then applied to the development of defensible pollution load management targets for a Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay.

Background

Tampa Bay is the largest estuary in the state of Florida. It extends approximately 35 miles into the west central coast of Florida (Figure 1), and is 5 to 10 miles wide along the majority of its length. Surface water flow from the 2,276-square-mile watershed is provided by the Hillsborough, Palm, Alafia, Little Manatee, and Manatee Rivers and over 40 minor tributaries. The mainstem of the bay is greatly affected by the exchange of seawater and nutrients to and from the Gulf of Mexico.

The biological systems of the estuary are characterized by both submerged and emergent vegetated habitats. The emergent vegetated habitats are dominated by a mosaic of mangrove forests and saltmarshes. Seagrass meadows are the dominant submerged vegetation of the estuary, and comprise *Thalassia*, *Syringodium*, *Halodule*, and *Ruppia*.

Due to development of its watershed, Tampa Bay experienced increases in pollutant loadings, declines in water quality, and loss of seagrass acreage between 1950 and the early 1980s. Long-term observations suggested that along with direct physical destruction for development (Janicki et al., 1994), pollutant loadings to Tampa Bay, and the associated decline in water quality, have contributed to a reduction in the extent of naturally occurring seagrass meadows (Lewis et al., 1985; Avery, 1991; Lewis et al., 1991). A major part of the poor water quality impacts on seagrasses is thought to be the attenuation of downwelling sunlight by excess concentrations of phytoplankton and suspended solids in the water column. Hence, the seagrass plants do not receive enough sunlight to remain healthy, and they perish. Recent applied research concerning the role of water quality in the loss of seagrass meadows was discussed in Morris and Tomasko (1992), Stevenson et al. (1993), and Batuik et al. (1992). Figures 2 and 3 present the extent of the loss of seagrass acreage between 1950 and 1990.

Due to the cooperative efforts of local and regional resource managers, the Tampa Bay Agency on Bay Management (ABM, 1989), private interests, and concerned citizens, pollutant loadings have been reduced and water quality has been improving in the bay since 1984. With the implementation of a number of different management actions in the early 1980s, including the implementation of advanced wastewater treatment technologies, chlorophyll levels have been declining from 1985 to present (Figure 4). Research on the recovery has suggested that a lag may exist in the recovery of seagrass meadows relative to the decline in seagrasses, and that seagrasses may continue to recover at a relatively slower rate (Johansson, 1991).

In 1991, the TBNEP was initiated as a cooperative program to continue this process of reducing pollutant loads, improving water quality, and restoring lost habitat. To provide an objective focus for pollutant load management targets, the participants in the program selected the acreage of seagrass meadows in the bay as a living resource benchmark by which progress could be measured. Recent observations by the Southwest Florida Water Management District have indicated that seagrass acreages have increased from 1990 to 1995, following the period of improved water quality. Thus, the important management questions for the TBNEP became:

1) How many acres of seagrass should be restored to return the bay to a restored state?

2) At what level should pollutant loads be managed to reach the seagrass acreage defined by question 1?

The TBNEP developed an ad hoc political consensus regarding the first question by establishing quantitative

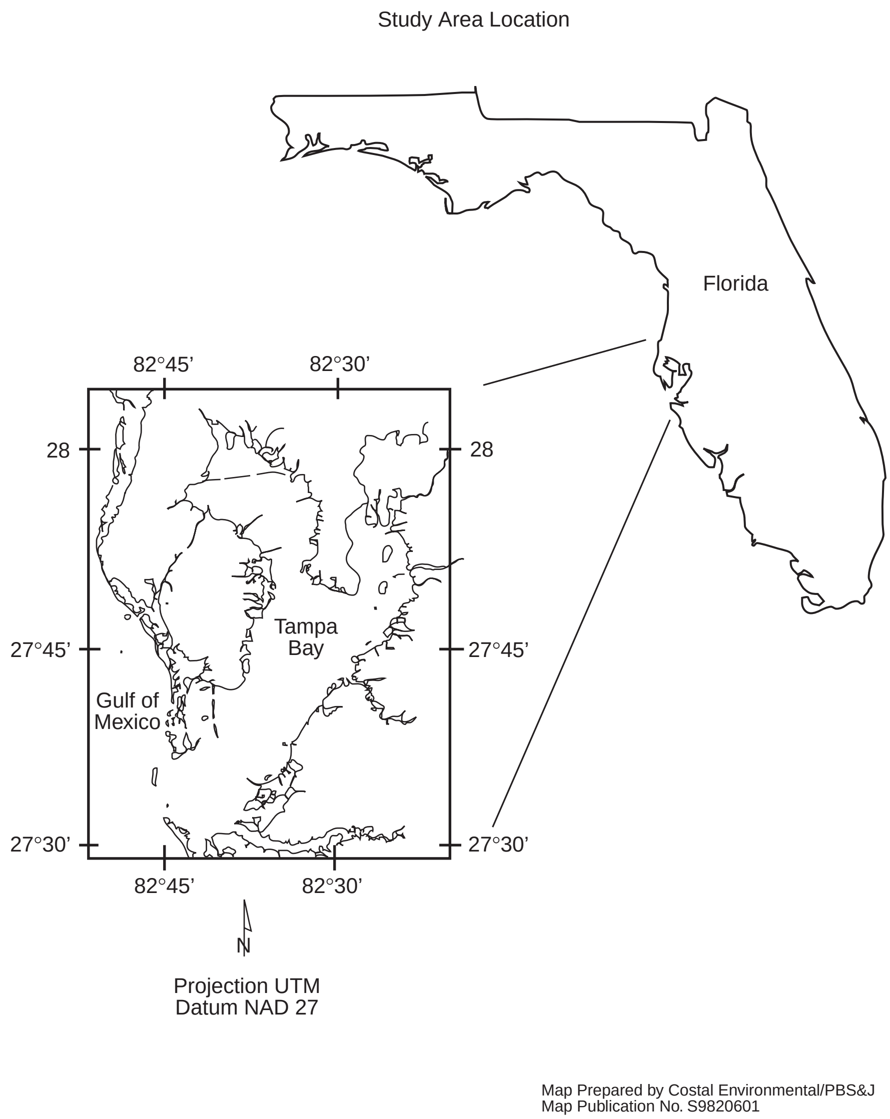

Figure 1. Tampa Bay National Estuary Program study area location.

seagrass restoration acreage targets. The target was set by mapping and enumerating the reduction in seagrass acreage from 1950 to 1990, and subtracting from this acreage the amount of seagrass that was permanently lost to physical impacts (e.g., channel dredging, island creation, borrow pits) and not likely to be restored (Janicki et al., 1994). The work for this paper was completed to answer the second question regarding what level of pollutant loads would be consistent with meeting this acreage target.

Objectives

The specific objective of this work was 1) to use the available data to document the relationships among loadings, water quality, and the subsurface light environments, and 2) to apply these empirical relationships to estimate pollution load management targets that would result in the maintenance of suitable light levels to restore the historical seagrass acreage within the bay.

A paradigm was developed to illustrate the management of nitrogen loads to effect changes in the acreage of seagrass meadows (Figure 5). Using this paradigm, external nitrogen loads to the bay result in increased nitrogen concentrations in the bay. The increased nitrogen concentrations lead to increased chlorophyll concentrations. The increased chlorophyll concentrations result in decreased depths to which surface light can penetrate in sufficient levels to maintain seagrass meadows, and the

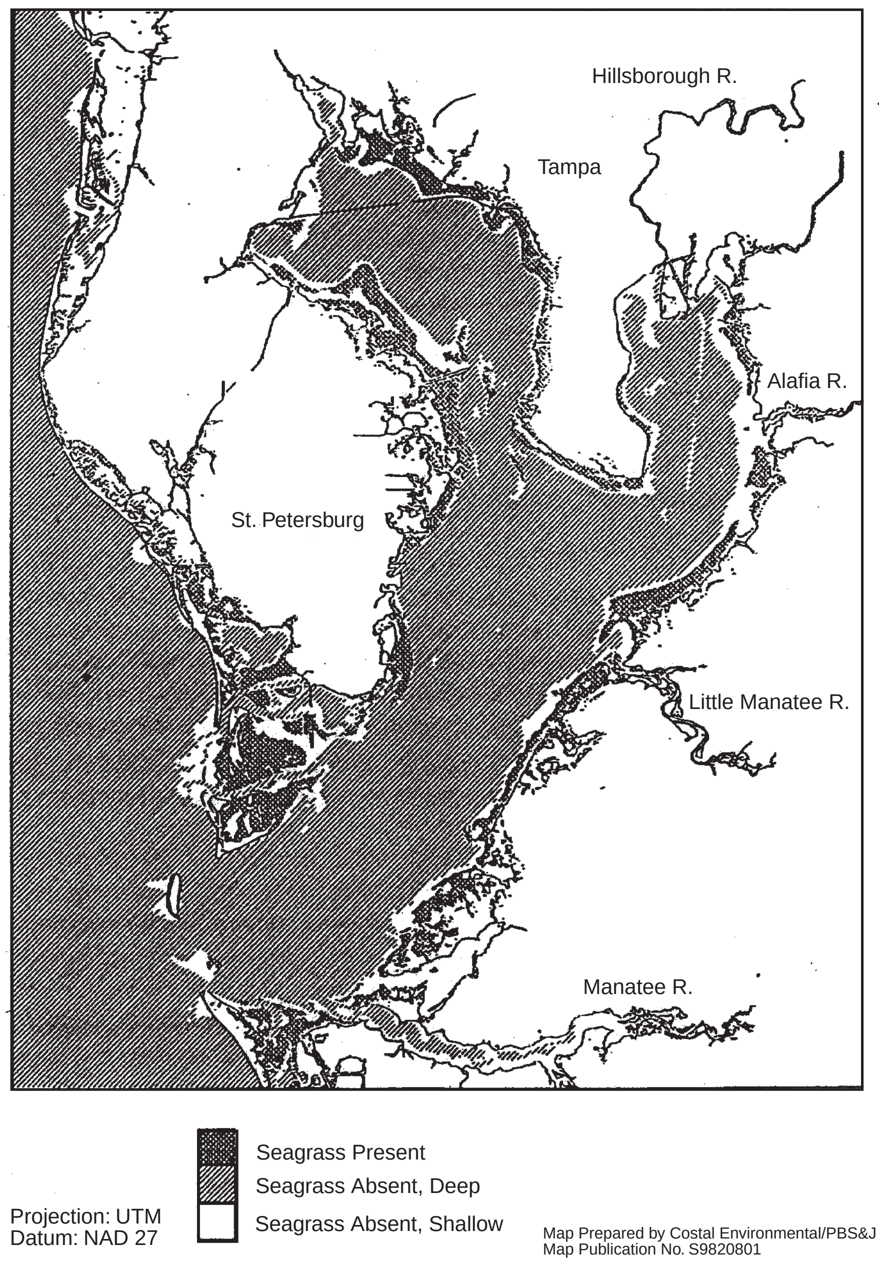

Figure 2. 1950 seagrass distribution in Tampa Bay.

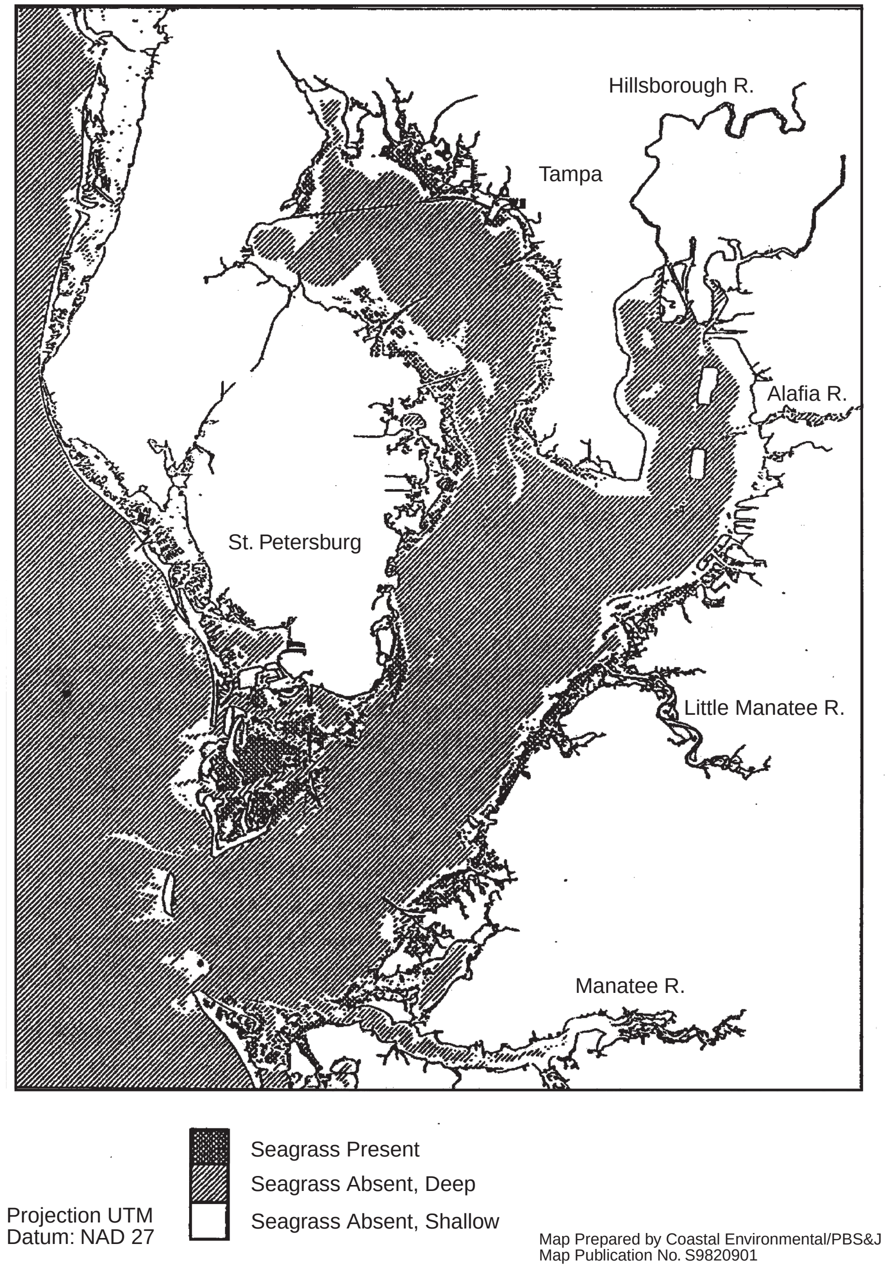

Figure 3. 1990 seagrass distribution in Tampa Bay.

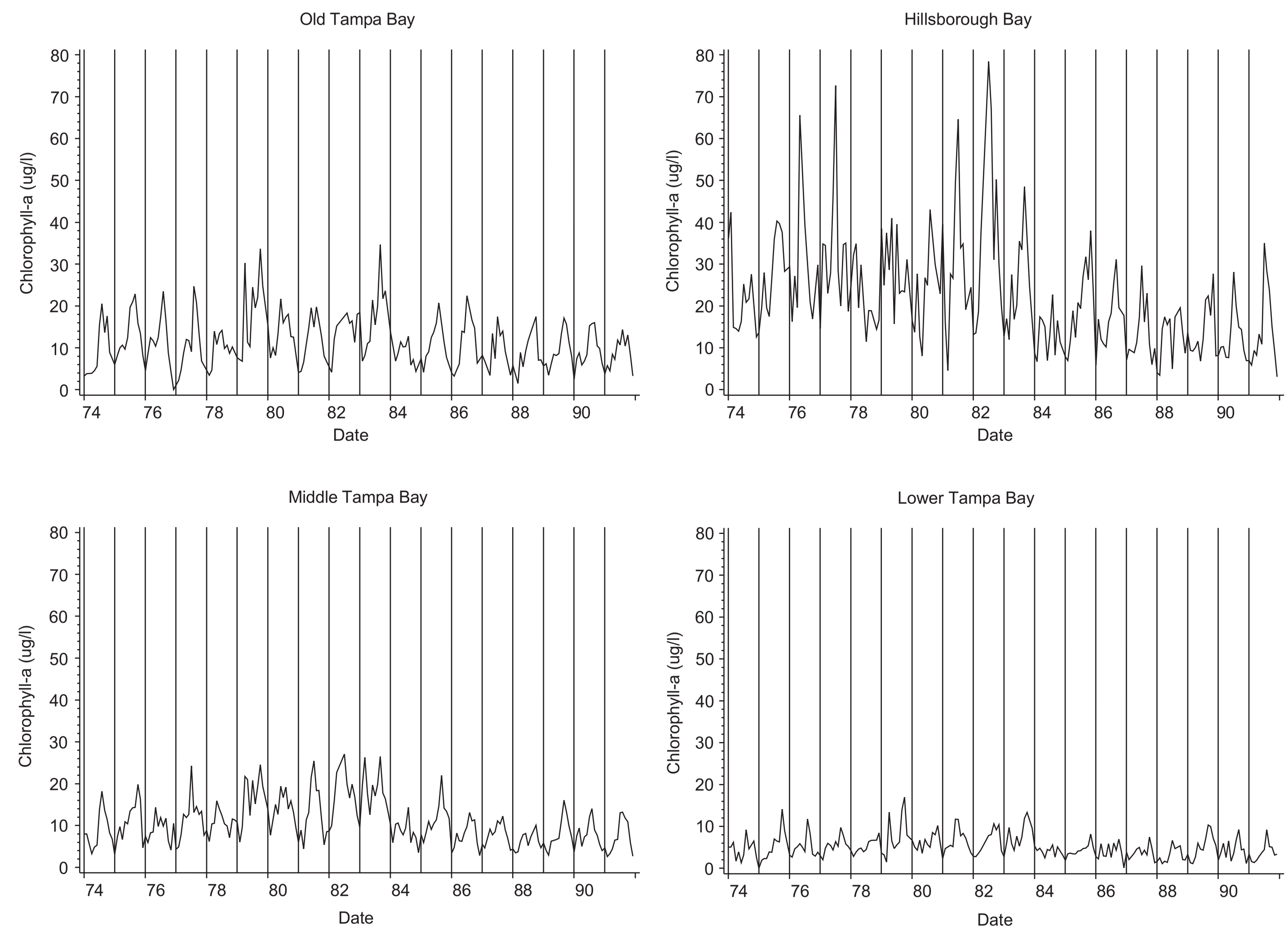

Figure 4. Historical trends in chlorophyll in Tampa Bay.

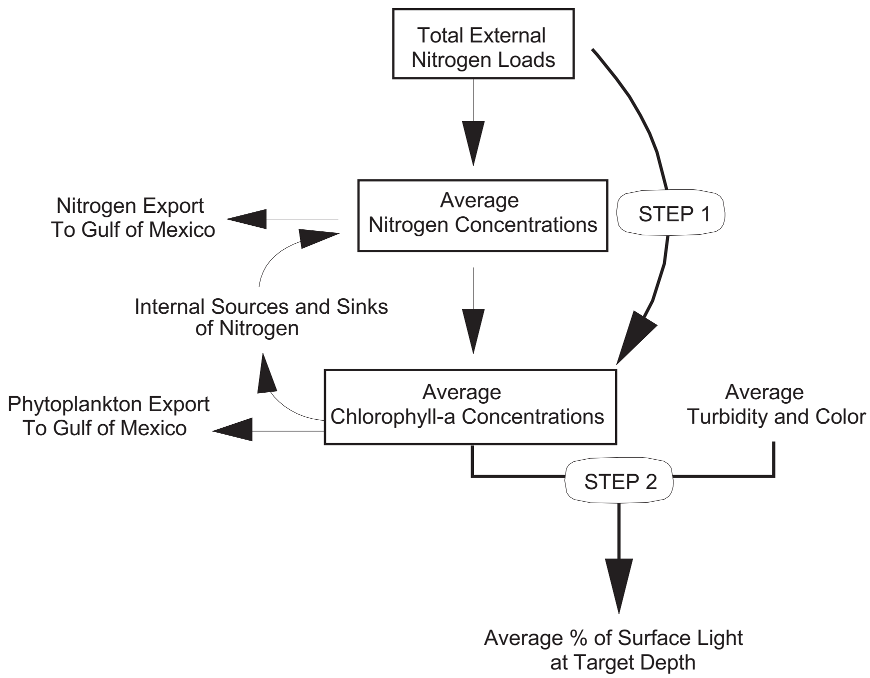

Figure 5. Empirical target setting approach paradigm.

decreased light levels result in reductions in the extent of seagrass meadows starting with the deeper meadows.

Thus, by using the available data to elucidate the links of this paradigm, the TBNEP was able to establish nitrogen load targets that would provide suitable light conditions to a desired number of acres of bay bottom that could potentially support seagrass meadows.

Methods

The first step in meeting this objective was to use the available data to quantify each of the links in the paradigm. Monthly external nitrogen load data were calculated and compiled by the TBNEP (Zarbock et al., 1994). Monthly water quality data, including nitrogen concentrations, chlorophyll concentrations, and light penetration data were used from 1986 to 1990, from data recorded by the Environmental Protection Commission of Hillsborough County. Seagrass data from the Southwest Florida Water Management District, restoration target areas from the TBNEP, and bathymetric data from the National Oceanographic and Atmospheric Administration (NOAA) were combined to quantify the restoration areas.

The final step in the approach was to apply the quantitative relationships of the paradigm to compute the nitrogen loading targets which were consistent with meeting the seagrass acreages targets.

Results

The available monthly data were sufficient to develop the links of the previously described paradigm.

Paradigm Link of Nitrogen Loads to Nitrogen Concentrations

A significant and useful relationship between monthly external nitrogen loads and monthly nitrogen concentrations in the bay (i.e., the first link in the paradigm) was not observed in the available data. Thus, a modification to the original paradigm was made to link the external nitrogen loads directly to chlorophyll concentrations. The relationships between nutrient loads and water quality have been the subject of classical limnological research (Vollenweider 1968, 1975, 1976) and more recent research for estuaries (Riley 1972, Boynton et al., 1982).

Paradigm Link of Nitrogen Loads to Chlorophyll Concentrations

Statistically significant relationships between monthly external nitrogen loads and monthly chlorophyll concentrations were observed in the available data, and were enumerated using data from 1986 to 1994. Monthly specific intercepts were used in the regression models to preclude problems with potential seasonal autocorrelation in the data. Figure 6 presents an example of these relationships. The overall R-square value for these relationships was 0.69.

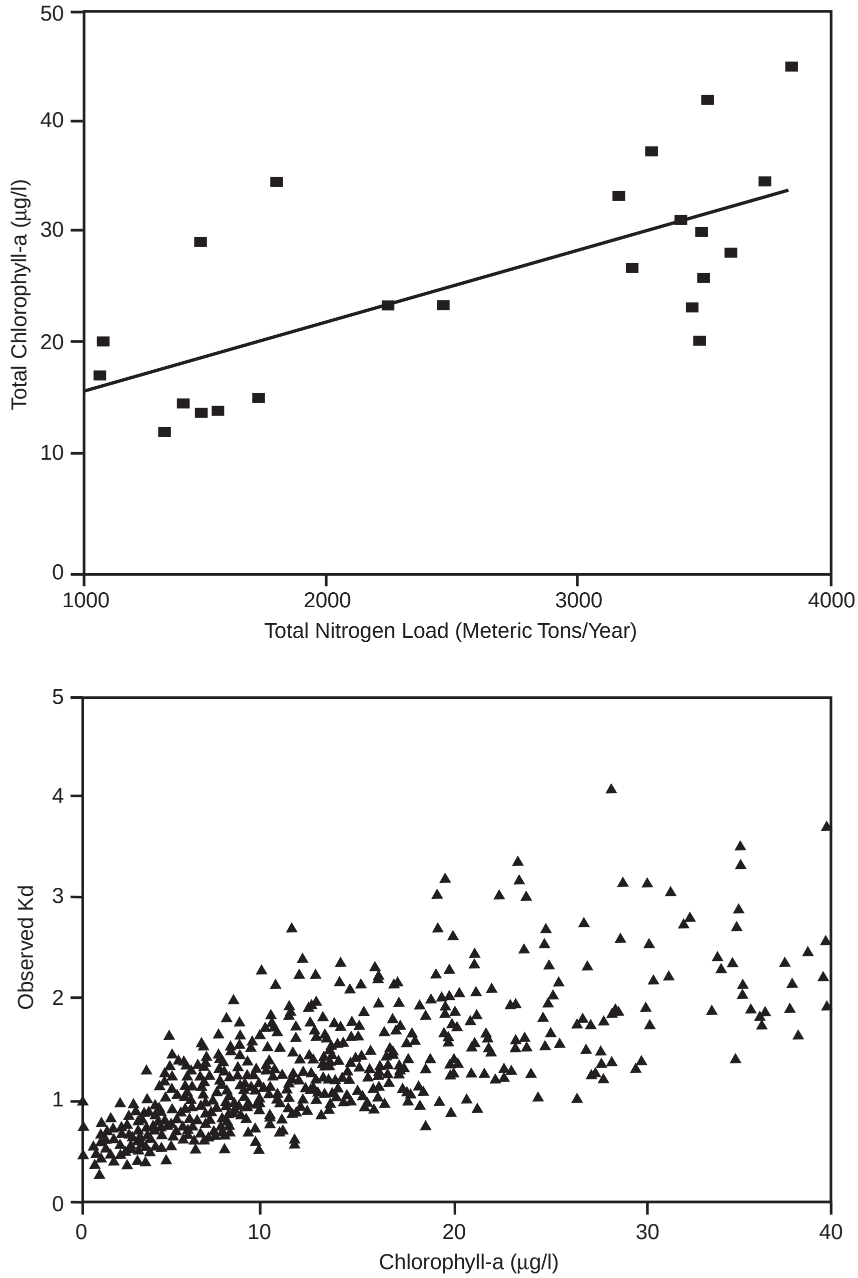

Figure 6. Resulting empirical relationships for links of the paradigm: a) the relationship of external nitrogen load to chlorophyll concentration in Hillsborough Bay, and b) the relationship of chlorophyll concentration to light attenuation in Hillsborough Bay.

The bay was divided into four segments for all steps of the paradigm. For each segment, the quantity of external nitrogen delivered to it was calculated as the input from the watershed and airshed plus the amount contributed through circulation from the other bay segments. The nitrogen loads from the watershed and airshed were calculated in a separate TBNEP study (Zarbock et al., 1994). The nitrogen contributed from circulation from the other bay segments was calculated by solving a series of steady-state dilution equations, using salt as a conservative tracer substance, and the observed salinity data for each segment and the Gulf of Mexico with the freshwater inflow data for each segment. An empirically fit parameter was used to correct these salt-derived equations for the nonconservative nature of nitrogen. This was done by comparing total nitrogen concentrations predicted by applying the conservative substance-derived dilution equations to actual nitrogen loads and comparing the predicted nitrogen concentrations with observed nitrogen concentrations. These relationships were statistically significant (overall R-square of 0.68), and indicated that for the period of 1986 to 1994, an average annual amount of approximately 8 to 9% more nitrogen was input to the upper segments of the bay than could be explained by loadings alone. A possible explanation for this observation is that nitrogen from the fine sediments of these segments was being liberated to the waters above. The nitrogen in the sediments likely accumulated during the pre-1985 period, during which external loads were higher.

Paradigm Link of Chlorophyll Concentrations to Light Attenuation

Statistically significant relationships were observed between observed monthly chlorophyll concentrations and light attenuation. As described below, the depth to which 20.5% of surface light is estimated to penetrate was selected as the light attenuation measurement for these relationships. As for the previous regression models, monthly specific intercepts were used to preclude potential seasonal autocorrelation in the observed data. Figure 6b presents an example of the relationship between these data. The overall R-square value for these relationships was 0.67. The TBNEP recognized that turbidity was also an important determinant of light penetration in the bay. However, chlorophyll concentrations are currently of greater concern to bay managers, and a very useful and statistically significant model could be developed using chlorophyll alone as an explanatory variable.

Paradigm Link of Light Attenuation to Seagrass Restoration

Because a large database of light attenuation data paired with seagrass condition data was not available, this final link of the paradigm was derived from observations from independent research conducted by the participating TBNEP scientists. A TBNEP study conducted for the Southwest Florida Water Management District by Mote Marine Laboratory (Dixon and Leverone, 1995) collected photosynthetically active radiation (PAR) measurements at the deep edges of seagrass beds in the lower portion of the bay for one year. After subtracting an average measured bottom reflectance of 2%, the TBNEP scientists reached a consensus that an annual average 20.5% of surface light was needed for seagrass survival in Tampa Bay.

Application of the Results to Nitrogen Load Targets

The empirically derived links of the paradigm were applied as a single tool to answer the second question defined above (i.e., at what level should nitrogen loads be managed to meet the seagrass acreage restoration targets set by the TBNEP).

A series of candidate 15-year nitrogen load schedules were applied to the integrated models and the resulting chlorophyll values were estimated. These chlorophyll values were then used to estimate the depth to which 20.5% of surface light would penetrate. The NOAA depth data and seagrass restoration areas were then applied to a detailed computer mapping system to calculate the acreage of seagrass restoration areas which would be illuminated at 20.5% of surface light under the estimated chlorophyll levels. As described previously, seagrass restoration areas were defined as those areas of the bay bottom which had seagrass meadows in 1950, did not have seagrass meadows in 1990, and were not physically altered so as to preclude the restoration of seagrass given a proper light regime.

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Alum Treatment of Stormwater Runoff - An Innovative BMP for Urban Runoff Problems

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Alum treatment of stormwater runoff was begun in 1986 as part of a lake restoration project at Lake Ella in Tallahassee, Florida in 1986. Our system provides treatment of stormwater runoff entering the lake by injecting liquid alum into major stormsewer lines on a flow-weighted basis during rain events. When added to runoff, alum forms non-toxic precipitates of $Al(OH)_3$ and $AlPO_4$ which combine with phosphorus, suspended solids and heavy metals, causing them to be rapidly removed from the treated water. The alum stormwater treatment system resulted in immediate and substantial improvements to water quality in Lake Ella which led to implementation of similar systems on other urban lakes. There are currently 23 alum stormwater treatment systems either operational or under construction in Florida, and one experimental system in Seattle, Washington.

Alum treatment of stormwater runoff has consistently achieved a 90% reduction in total phosphorus, 50-70% reduction in total nitrogen, 50-90% reduction in heavy metals, and >99% reduction in fecal coliform. Ultimate water quality improvements in the receiving water body have been related to the percentage of total inputs treated by the system. Heavy metal and phosphorus associations with alum floc have been shown to be extremely stable over a wide range of pH and redox conditions.

In general, alum treatment of runoff is substantially less expensive than traditional treatment methods and often requires no additional land purchase. Recent designs have incorporated automatic floc collection and removal systems with disposal to drying beds or sanitary sewer.

Introduction

The addition of alum to water results in the production of chemical precipitates which remove pollutants by two primary mechanisms. Removal of suspended solids, algae, phosphorus, heavy metals and bacteria occurs primarily by enmeshment and adsorption onto aluminum hydroxide precipitate according to the following net reaction:

$$Al^{+3} + 6H_2O \rightarrow Al(OH)_{3(s)} + 3H_3O^+$$

Removal of additional dissolved phosphorus occurs as a result of direct formation of $AlPO_4$ by:

$$Al^{+3} + HnPO_4^{n-3} \rightarrow AlPO_{4(s)} + Hn^+$$

The aluminum hydroxide precipitate, $Al(OH)_3$, is a gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc, thus clarifying the water. Phosphorus removal or entrapment can occur by several mechanisms, depending on the solution pH. Inorganic phosphorus is also effectively removed by adsorption to the Al(OH)3 floc. Removal of particulate phosphorus is most effective in the pH range of 6-8 where maximum floc occurs (Cooke and Kennedy, 1981). At higher pH values, OH^- begins to compete with phosphate ions for aluminum ions, and aluminum hydroxide-phosphate complexes begin to form. At lower pH values and higher inorganic phosphorus concentrations, the formation of aluminum phosphate ($AlPO_4$) is favored.

In 1985, a lake restoration project was initiated at Lake Ella, a shallow 13.3-acre hypereutrophic lake in Tallahassee, Florida, which receives untreated stormwater runoff from approximately 163 acres of highly impervious urban watershed area. Initially, conventional stormwater treatment technologies, including retention basins, exfiltration trenches and filter systems, were considered for reducing available stormwater loadings to Lake Ella in an effort to improve water quality within the lake. Since there was no available land surrounding Lake Ella that could be used for construction of traditional stormwater management facilities, and the purchasing of homes and businesses to acquire land for construction of these facilities was cost-prohibitive, alternate stormwater treatment methods were considered.

Chemical treatment of stormwater runoff was evaluated using various chemical coagulants, including aluminum sulfate, ferric salts, and polymers. Aluminum sulfate (alum) consistently provided the highest removal efficiencies and produced the most stable end product. In view of successful jar test results on runoff samples collected from the Lake Ella watershed, the design of a prototype alum injection stormwater system was completed. Construction of the Lake Ella alum stormwater treatment system was completed in January 1987, resulting in a significant improvement in water quality.

The alum precipitate formed during coagulation of stormwater can be allowed to settle in receiving waterbodies or collected in small settling basins. Alum precipitates are exceptionally stable in sediments and will not redissolve due to changes in redox potential or pH under conditions normally found in surface waterbodies. Over time, the freshly precipitated floc ages into even more stable complexes, eventually forming gibsite. The solubility of dissolved aluminum in the treated water is regulated entirely by chemical equilibrium. As long as the pH of the treated water is maintained within the range of 5.5-7.5, dissolved aluminum concentrations will be minimal. In many instances, the concentration of dissolved aluminum in the treated water will be less than the concentration in the raw untreated water due to adjustment of pH into the range of minimum solubility.

Since the Lake Ella system, alum stormwater treatment systems have been constructed in Florida for Lake Dot, Lake Rowena and Lake Lucerne in Orlando; Lake Osceola, Lake Virginia North and Lake Mizell in Winter Park; Lake Cannon in Polk County; Channel 2 Drainage Canal in Pinellas Park; Celebration Town Lake in Celebration; Lake Holden in Orange County; Lake Tuskawilla in Ocala; and a set of five separate systems has been installed at Lake Maggiore in St. Petersburg. An experimental treatment facility has also been constructed in the Lake Sammamish watershed in Seattle, Washington. In addition to these projects which are currently operational, additional projects are currently under design in Winter Park, Orlando, Largo, Tampa and Clearwater. The first project to treat stormwater discharged to a brackish water became operational in January 1998 in the City of St. Petersburg, Florida.

Alum treatment of stormwater runoff has now been used as a viable stormwater treatment alternative in urban areas for over 10 years. Over that time, a large amount of information has been collected relative to optimum system configuration, water chemistry, sediment accumulation and stability, construction and operation costs, comparisons with other stormwater management techniques, and floc collection and disposal. A summary of current knowledge in these areas is given in the following sections.

System Configuration

Once alum has been chosen as an option in a stormwater retrofit project, extensive laboratory testing must be performed to verify feasibility and to establish design parameters. The feasibility of alum treatment for a particular stormwater stream is typically evaluated in a series of laboratory jar tests conducted on representative runoff samples collected from the project watershed area. This extensive laboratory testing is necessary to determine design, maintenance and operational parameters such as the optimum coagulant dose required to achieve the desired water quality goals, chemical pumping rates and pump sizes, the need for additional chemicals to buffer the pH of receiving water, post-treatment water quality characteristics, floc formation and settling characteristics, floc accumulation, annual chemical costs and storage requirements, ecological effects, and maintenance procedures. In addition to determining the optimum coagulant dose, jar tests can also be used to determine floc strength and stability, required mixing intensity and duration, and design criteria for dedicated floc settling basins.

In a typical alum stormwater treatment system, alum is added to the stormwater flow on a flow-proportional basis so that the same dose of alum is added to a gallon of stormwater flow regardless of the discharge rate. A variable speed chemical metering pump is typically used as the injection pump. If a buffering agent, such as NaOH, is required to maintain desired pH levels, a separate metering system and storage tank will be necessary. The operation of each injection pump is regulated by a flow meter device attached to each incoming stormwater line to be treated. Data from each stormwater flow meter is transformed into a 4-20 mA electronic signal which instructs each metering pump to inject alum according to the measured flow through each individual line. Mixing of the alum and stormwater occurs as a result of turbulence in the stormsewer line. If sufficient turbulence is not available within the stormsewer line, artificial turbulence can be generated using aeration or physical stormsewer modifications.

Mechanical components for the alum stormwater treatment system, including chemical metering pumps, stormsewer flow meters and electronic controls, are typically housed in a central facility which can be constructed as an above-ground or below-ground structure. A 6,000 gallon tank is typically used for bulk alum storage. Alum feed lines and electrical conduits are run from the central facility to each point of flow measurement and alum addition. Alum injection points can be located as far as 3000 ft from the central pumping facility. Early designs for alum stormwater treatment systems utilized individual chemical metering pumps and stormsewer flow meters for each point of alum addition. However, in an effort to reduce overall system costs and complexity, current alum stormwater treatment systems often feed alum to multiple points using a single chemical metering pump and control valves.

Water Chemistry

In general, construction and operation of alum stormwater treatment systems has resulted in significant improvements in water quality for treated waterbodies. The degree of observed improvement in water quality is directly related to the percentage of annual hydraulic inputs treated by the alum stormwater treatment system. A comparison of pre- and post-modification water quality for three typical alum stormwater treatment systems is given in Table 1, including Lake Ella and Lake Dot (which provide treatment for approximately 95-96% of the annual hydraulic inputs entering these lake systems), and Lake Osceola (which provides treatment for only 9% of the annual hydraulic inputs entering the lake system).

Operation of the alum stormwater treatment systems resulted in a decline in pH within each of the three waterbodies, ranging from a reduction of approximately 1 unit in Lake Ella to 0.6 units in Lake Osceola. A pH reduction of only 0.1 unit was observed for the Lake Dot treatment system which injects alum in combination with sodium hydroxide to control pH levels within the lake. In addition, significant improvements in dissolved oxygen were observed in both Lake Ella and Lake Dot. Alum treatment of stormwater runoff resulted in a 78% reduction in total nitrogen concentrations in Lake Ella, a 55% reduction in Lake Dot and a 4% reduction in Lake Osceola where only a small portion of the annual hydraulic inputs are treated. The majority of the total nitrogen removal observed is a result of reducing concentrations of dissolved organic nitrogen and particulate nitrogen, since alum is generally ineffective in reducing concentrations of inorganic nitrogen species, such as ammonia or NO_x. Alum stormwater treatment resulted in a substantial reduction in measured concentrations of orthophosphorus and total phosphorus in each of the three lake systems, with total removals of 89%, 93% and 30% for Lake Ella, Lake Dot and Lake Osceola, respectively. Alum stormwater treatment also reduced in-lake concentrations of BOD in each of the three lake systems, with a reduction of 93% in Lake Ella, 84% in Lake Dot and 22% in Lake Osceola.

Alum stormwater treatment has been extremely effective in reducing concentrations of chlorophyll-a in receiving waterbodies, with a reduction of 97% in Lake Ella, 89% in Lake Dot and 13% in Lake Osceola. Reductions in measured concentrations of chlorophyll-a occur as a result of enmeshment and precipitation of algal particles within the water column of the lake by alum floc as well as phosphorus limitation created by low levels of available phosphorus in the water column. Substantial increases in Secchi disk depth were observed in Lake Ella and Lake Dot, and to a lesser extent in Lake Osceola, with improvements of 340% in Lake Ella, 212% in Lake Dot and 9% in Lake Osceola. Based upon the Florida TSI Index (Brezonik, 1984), Lake Ella and Lake Dot have been converted from hypereutrophic to oligotrophic status, with a conversion from eutrophic to mesotrophic the case in Lake Osceola.

A graphic history of total phosphorus concentrations in Lake Lucerne, which was retrofitted with an alum stormwater treatment system in June 1993 that provides treatment for approximately 82% of the annual runoff inputs into the lake, is given in Figure 1. Prior to construction of the alum stormwater treatment system, total phosphorus concentrations in Lake Lucerne fluctuated widely, with a mean concentration of approximately 100 µg/l. Following start-up of the alum treatment system, total phosphorus concentrations began to decline steadily, reaching equilibrium concentrations of 20-40 µg/l. A slight increase in total phosphorus concentrations was observed during the last half of 1995 when the system was off-line due to lightning damage. When system operation resumed in June

Table 1. Comparison of Pre- and Post-Modification Water Quality Characteristics for Typical Alum Stormwater Treatment Systems

PARAMETER	UNITS	LAKE ELLA BEFORE (1974-85)	LAKE ELLA AFTER (1/88-5/90)	LAKE DOT BEFORE (1986-88)	LAKE DOT AFTER (3/89-8/91)	LAKE OSCEOLA BEFORE (6/91-6/92)	LAKE OSCEOLA AFTER (2/93-12/96)
# of Samples	–	15	11	5	15	12	46
pH	s.u.	7.41	6.43	7.27	7.17	8.22	7.63
Diss. O_2 (1 m)	mg/l	3.5	7.4	6.6	8.8	8.8	8.8
Total N	µg/l	1876	417	1545	696	892	856
Total P	µg/l	232	26	351	24	37	26
BOD	mg/l	41	3.0	16.8	2.7	4.4	3.4
Chlorophyll-a	mg/m^3	180	5.1	55.8	6.3	24.8	21.7
Secchi Disk Depth	m	0.5	> 2.2	< 0.8	2.5	1.1	1.2
Diss. Al	µg/l	–	44	–	65	18	51
Florida TSI Value	_	98 (Hyper-eutrophic)	47 (Oligotrophic)	86 (Hyper-eutrophic)	42 (Oligotrophic)	61 (Eutrophic)	56 (Meso-trophic)
Lake Area	–	13.3 ac		5.9 ac		55.4 ac	
Watershed Area	–	57 ac		305 ac		153 ac	
Percent of Annual Hydraulic Inputs Treated	%	95		96		9	

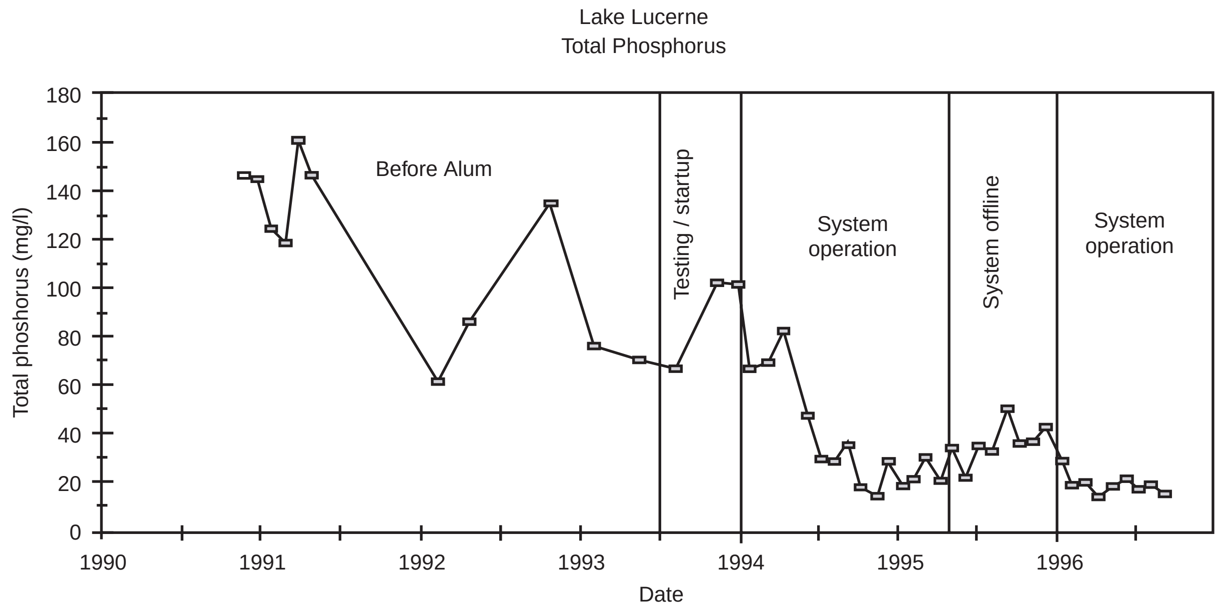

Figure 1. Trends in total phosphorus concentrations in Lake Lucerne before and after alum treatment of stormwater runoff.

1996, total phosphorus concentrations returned to equilibrium values of approximately 20 µg/l.

In general, measured concentrations of heavy metals have been extremely low in value in all waterbodies retrofitted with alum stormwater treatment systems, with no violations of heavy metal standards. In addition, measured levels of dissolved aluminum have also remained low in each lake system. Mean dissolved aluminum concentrations for Lake Ella, Lake Dot and Lake Osceola have averaged 44 µg/l, 65 µg/l and 51 µg/l, respectively. Although there is no standard for dissolved aluminum in the State of Florida, the U.S. EPA has recommended a long-term average of 87 µg/l for protection of all species present in the U.S. The solubility of dissolved aluminum is regulated almost exclusively by pH. As long as the pH of the treated water can be maintained in the range of 6.0-7.5 during the treatment process, dissolved aluminum concentrations will remain at minimal levels.

Floc Accumulation

Laboratory investigations have been conducted on stormwater runoff collected from a wide range of land uses typical of urban areas to quantify the amount of alum floc generated as a result of alum treatment of stormwater runoff at various treatment doses. After initial formation, alum floc appears to consolidate rapidly for a period of approximately 6-8 days, reaching approximately 20% of the initial floc volume. Additional consolidation appears to occur over a settling period of approximately 30 days, after which collected sludge volumes appear to approach maximum consolidation (Harper, 1990).

Estimates of maximum anticipated sludge production, based upon literally hundreds of laboratory tests involving coagulation of stormwater runoff with alum at various doses, and based upon a consolidation period of approximately 30 days, are given in Table 2. At alum doses typically used for treatment of stormwater runoff, ranging from 5-10 mg/l as Al, sludge production is equivalent to approximately 0.16-0.28% of the treated runoff flow. Sludge production values listed in Table 2 reflect the combined mass generated by alum floc as well as solids originating from the stormwater sample.

Field investigations have also been performed in lake systems receiving alum treated stormwater runoff to document the accumulation rate of alum floc within the sediments by visual inspection of sediment core samples collected in clear acrylic tubes at selected monitoring sites in each lake. A comparison of observed and predicted floc accumulation rates in lake systems receiving stormwater treatment is given in Table 3. Each of the listed lakes has been receiving alum treatment for five years or more. The primary predicted settling area for floc accumulation was determined by evaluating lake bottom topography and stormsewer inflow characteristics. Predicted floc accumu-

Table 2. Anticipated Production of Alum Sludge from Alum Treatment of Stormwater at Various Doses

	Sludge Production[1]	
Alum Dose (mg/l as Al)	As Percent Of Treated Flow	Per 10^6 Gallons Treated
5	0.16	214 ft^3
7.5	0.20	268 ft^3
10	0.28	374 ft^3

[1]Based on a minimum settling time of 30 days

Table 3. Comparison of Observed and Predicted Floc Accumulation Rates in Lake Systems with Alum Stormwater Treatment

Lake	Predicted Settling Area	Predicted Accumulation Rate	Observed Accumulation Rate
Lake Ella	50% of lake bottom	1 cm/yr	0.33 cm/yr
Lake Lucerne	areas 10 ft or deeper	3.3 cm/yr	none
Lake Osceola	50% of lake bottom	0.5 cm/yr	none

lation rates are based upon the anticipated floc production rates summarized in Table 2.

Annual floc production in Lake Ella was predicted to be approximately 1 cm/yr over 50% of the lake bottom. However, floc accumulation evaluations performed in 1990 indicate an observed accumulation rate of approximately 0.33 cm/yr, approximately one-third of the predicted accumulation rate. The reduced observed accumulation rate is thought to be a result of additional floc consolidation over time and incorporation of the alum floc into the existing sediments. The observed post-treatment floc accumulation rate in Lake Ella is similar to the pre-treatment sediment accumulation rate in Lake Ella resulting from the extremely high algal production prior to the lake restoration efforts in 1985. Sediment accumulation in Lake Lucerne was anticipated to occur in areas 10 ft or deeper, with a predicted accumulation of 3.3 cm/yr. However, no sediment accumulation was observed at any of the 10 fixed monitoring locations within the lake which have contributed data on an annual basis since start-up of the alum treatment system. A similar conclusion has been reached in Lake Osceola which has no visible floc accumulation after approximately five years of alum stormwater treatment. Both Lake Lucerne and Lake Osceola appear to incorporate alum floc into the existing sediments with no visible surface floc layer.

Construction and O&M Costs

A summary of construction and annual operation and maintenance (O&M) costs for existing alum stormwater treatment facilities, with treated watershed areas ranging from 64 ac to 1450 ac, is given in Table 4. Construction costs for alum stormwater treatment systems have ranged from $75,000 to $400,000, depending upon the number of outfalls to be retrofitted. In general, the capital cost of constructing alum stormwater treatment systems is independent of the watershed size since the capital cost for constructing a treatment system for a 100-acre watershed is identical to the cost of constructing a system to treat 1000 acres at the same location, although annual O&M costs would differ. The average capital cost for existing alum stormwater treatment facilities is $245,998.

Estimated O&M costs are also provided in Table 4 and include chemical, power, manpower for routine inspections, and equipment renewal and replacement costs. Operation and maintenance costs for existing alum stormwater treatment systems range from $5,500 to $26,298 per year. Construction costs and annual O&M costs are also included on a per acre treated basis for comparison with other stormwater treatment alternatives.

Comparison with Other Stormwater Treatment Alternatives

In general, removal efficiencies obtained with alum stormwater treatment are similar to removal efficiencies obtained using a dry retention or wet detention stormwater management facility. A comparison of treatment efficiencies for common stormwater management systems is given in Table 5 (Harper, 1995). Estimated removal efficiencies for alum treatment exceed removal efficiencies achieved in dry retention for total phosphorus and TSS, but fall short of dry retention for total nitrogen and BOD. Dry retention

Table 4. Summary of Construction and O&M Costs for Existing Alum Stormwater Treatment Facilities

Project	Area Treated (ac)	Construction Cost/System ($)	Estimated Annual O&M Cost ($)	Construction Cost Per Area Treated ($/ac)	Annual O&M Cost Per Area Treated ($/ac)
Lake Ella	158	200,400	–	1268	–
Lake Dot	305	250,000	–	823	–
Lake Lucerne	272	400,000	16,000	1472	59
Lake Osceola	153	300,000	6500	1959	43
Lake Cannon	490	135,000,	13,100,	276	27
Channe 2	84	180,000	–	2144	–
Lake Virginia North	64	242,000	–	3769	–
Celebration	158	300,000	25,000	1898	158
Lake Holden	183	292,000	–	1598	–
Lake Tuskawilla	311	242,000	19,627	777	63
Lake Rowena	538	75,000	–	139	–
Lake Mizell	74	300,000	15,389	4049	208
Lake Maggiore (5)	1450	400,000	21,450	1379	74
Webster Avenue	91	130,000	12,397	1423	136
Lake Virginia South	437	288,000	–	659	–
Merritt Ridge	195	201,575	26,298	1033	135
AVERAGES	310	$ 245,998	$17,307	$1542	$100

Table 5. Estimated Removal Efficiencies for Common Stormwater Management Systems

Type of System	Estimated Removal Efficiencies (%) Total N	Total P	TSS	BOD
Dry Retention (0.50-in runoff)	80	80	80	80
Wet Detention	20-30	60-70	85	50-60
Wet Detention with Filtration	0	60	>90	90
Dry Detention	10-20	20-40	60-80	03-50
Dry Detention with Filtration	0-20	0-20	60-90	0-55
Alum Treatment	50-70	>90	>95	60

may be the more effective common stormwater management technique in use today, if other things are equal. But certainly, removal efficiencies achieved with alum treatment exceed removal efficiencies obtained using wet detention, wet detention with filtration, dry detention, or dry detention with filtration. Alum is the best choice where space for retention cannot be built.

Alum treatment of stormwater runoff compares favorably with other stormwater treatment alternatives with respect to both initial capital construction costs and annual O&M costs. A comparison of certain costs for alum stormwater treatment and equivalent retention facilities is given in Table 6. Initial capital construction costs and annual O&M costs for three existing alum stormwater treatment facilities are compared with the estimated cost for construction of an alternate retention facility for treatment of the first 0.5 in of runoff. Each of the alternate retention facilities would require purchase of land in heavily urbanized areas which if available, would be expensive. The cost listed for the alternate retention facilities include land costs only and not actual construction costs. Estimated annual O&M costs for retention pond maintenance, such as routine mowing, weed control and trash removal, is higher than the estimated O&M costs for the alum treatment systems which include chemicals, weekly inspections, and parts and supplies.

Table 6. Comparison of Certain Costs for Alum Stormwater Treatment and Equivalent Retention Facilities

	Alum Treatment System			Equivalent Retention Facility		
Location	Area Treated (ac)	Capital Costs ($)	Annual O&M Costs[1] ($)	Land Area Required[2] (ac)	Land Costs ($)	Annual O&M Costs[3] ($)
Lake Osceola	88	235,000	6500	3.0	1,500,000[4]	9000
Lake Lucerne	210	420,000	16,000	7.3	3700,000[4]	21,900
Lake Cannon	490	135,000	13,100	17.0	850,000[5]	51,000

[1] Includes chemical costs, weekly inspection, and $1000 for supplies and parts
[2] Based on equivalent treatment of 1 inch of runoff and a 3-ft deep pond
[3] Based on $3000/acre for O&M (Ref; FDOT)
[4] Based on a land cost of $500,000/acre
[5] Based on a land cost of $50,000/acre

Floc Collection and Disposal

Although virtually all existing alum stormwater treatment systems allow for floc settling in receiving waterbodies, and although only beneficial aspects of alum floc accumulation have been observed, current alum treatment system designs feature collection and disposal of floc. Where possible, sump areas have been constructed to provide a basin for collection and accumulation of alum floc. The accumulated floc can then be pumped out of the sump area, using either manual or automatic techniques, on a periodic basis. Several current treatment systems provide for automatic floc disposal into the sanitary sewer system at a slow controlled rate. Since alum floc is virtually inert and has a consistency similar to that of water, acceptance of alum floc on a periodic basis poses no operational problem for wastewater treatment facilities. A schematic of a settling pond designed for the Lake Virginia system is included in Figure 2.

A recent design for collection of floc discharging from a submerged pipe in a lake system is also illustrated in Figure 2. The floc containment area consists of a fabric mesh sized to allow water flow while trapping floc particles. The floc is then collected in the sump area in the bottom of the containment area and pumped on a periodic basis to the sanitary sewer system or adjacent drying bed. Drying characteristics for alum sludge are similar to a wastewater treatment plant sludge. A drying time of approximately 30 days is sufficient to dewater and dry the sludge, with a corresponding volume reduction of 80-90%. Dried alum sludge has chemical characteristics suitable for general land application or in agricultural sites, as outlined in Chapter 62 of the Florida Administration Code (Florida Department of Environmental Protection, 1996).

Conclusions

Alum treatment of stormwater runoff has emerged as a viable and cost-effective alternative for providing stormwater retrofit in urban areas. Based upon 10 years of experience with alum stormwater treatment, the following conclusions have been reached:

- In lake systems where a large percentage of the annual runoff inputs are retrofitted with an alum treatment system, alum treatment has consistently achieved a 90% reduction in total phosphorus, 50-70% reduction in total nitrogen, 50-90% reduction in heavy metals, and >99% reduction in fecal coliforms. Ultimate water quality improvements in the receiving waterbodies are highly correlated with the percentage of total inputs treated by the system.
- The observed accumulation rate of alum floc in the sediments of receiving waterbodies are to be substan-

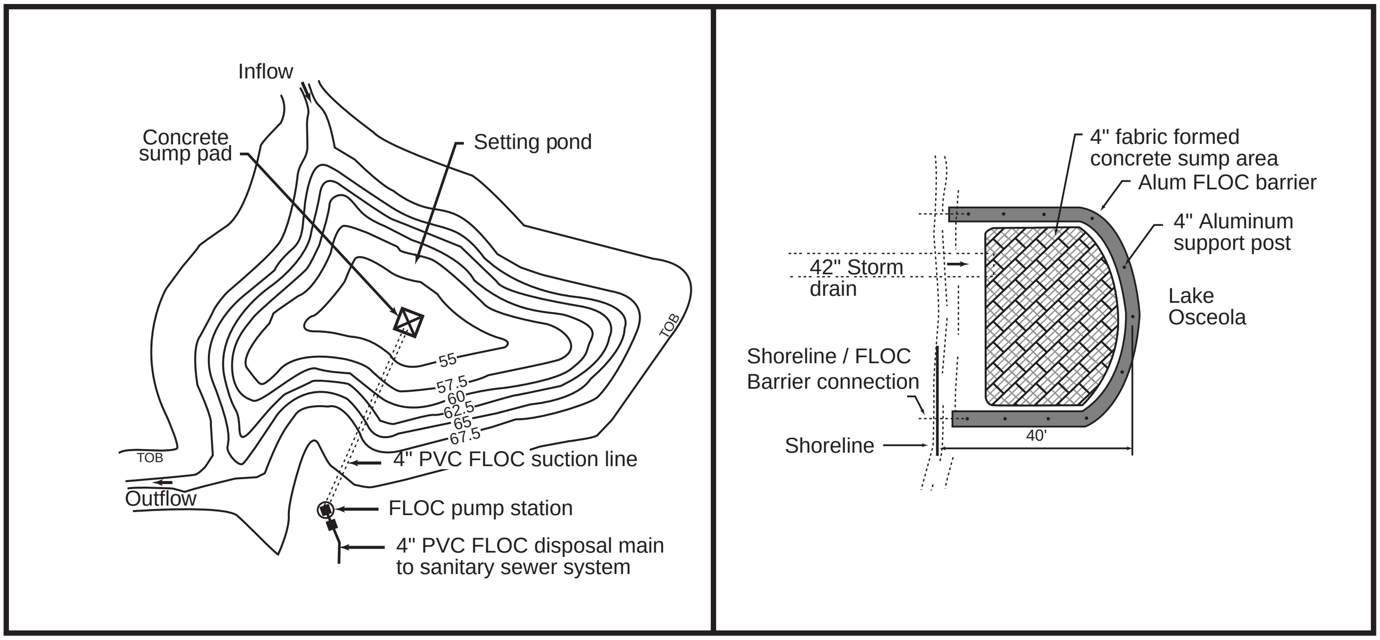

Figure 2. Typical schematics of floc collection and disposal systems.

tially lower than the predicted accumulation rate due to additional floc consolidation over time and incorporation of alum floc into the existing sediment.

- Construction costs for alum stormwater treatment systems are largely independent of the watershed area to be treated and depend primarily upon the number of outfalls to be retrofitted.
- In general, removal efficiencies obtained with alum stormwater treatment are roughly similar to removals obtained using a dry retention, and better than alternative stormwater management facilities.
- Alum treatment of stormwater runoff is often substantially less expensive than other stormwater treatment alternatives with respect to both initial capital costs and annual O&M costs.
- Several innovative designs have been developed for collection of alum floc in sump areas and containment areas, with floc disposal made to sanitary sewer or adjacent drying beds.

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An Eight-Step Approach to Implementing Stormwater Retrofitting

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What are retrofits and why are they important? In the quest for watershed protection and restoration, watershed professionals are constantly seeking new tools for controlling stormwater runoff and associated adverse impacts. Stormwater retrofits are among the most promising of these tools. Retrofits are structural stormwater management measures for urban watersheds designed to help lessen accelerated channel erosion, reduce pollutant loads, promote conditions for improved aquatic habitat, and correct past mistakes. Simply put, these best management practices (BMPs) are inserted in an urban landscape where limited stormwater controls existed.

Retrofits come in many shapes and sizes from large regional retention ponds that provide a variety of controls to small on-site facilities providing only water quality treatment for smaller storms. At least some kind of practice can be installed in almost any situation. But fiscal restraints, pollutant removal capability, and watershed capture area must all be carefully considered in any retrofit selection criteria.

Restoration versus Retrofitting

Stormwater retrofits should be applied along with other available watershed restoration strategies for reducing pollutants, restoring habitat and stabilizing stream morphology as part of a holistic watershed restoration program. While some professionals rightfully assert that true watershed restoration is not feasible, the term is applied here as simply a concerted strategy to install a functional native biological community in a stream, lake or river. Some of the many watershed restoration strategies include:

- Stabilizing stream channel morphology
- Improving aquatic habitat within urban streams
- Replacing or enhancing riparian cover along urban streams
- Promoting pollution prevention source controls within the watershed
- Recolonizing streams with native fish communities

Many, if not most, of these components should be planned in conjunction with an urban retrofit program. Without establishing a stable, predictable hydrologic water regime that regulates the volume, duration, frequency, and rate of flow, many of these other strategies may be disappointing failures. To successfully restore a stream's overall aquatic health, stormwater retrofitting is an essential element.

Table 1 presents a step-by-step approach to stormwater retrofitting developed by our Center for Watershed Protection staff over the past several years. An eight-step process is briefly discussed and several case studies from the author's experience emphasize particular points. At the conclusion of the eight-step process, two additional case studies are presented in more detail to illustrate some of the many real world challenges of implementing retrofit projects.

Step 1. Watershed Retrofit Site Inventory

The first step in getting retrofits "in the ground" is the process of locating and identifying where it is feasible and appropriate to put them. This involves a process of identifying as many potential sites as rapidly as possible. The best retrofit sites fit easily into the existing landscape, are located at or near major drainage or stormwater control facilities, and are easily accessible. For example, almost every urban area has some type of existing pond or other feature that might be adaptable for retrofitting. In many newer neighborhoods, dry stormwater detention facilities are present for flood control. In older neighborhoods there are often aesthetic ponds, or other water features which can make suitable retrofits. Table 2 lists some of the most likely spots for locating facilities, some common applications, and applicable case studies.

Usually the first step is completed in the office using available topographic mapping (a 5-ft contour interval is quite satisfactory), low altitude aerial photographs (where available), storm drain master plans, and land use maps (zoning or tax maps are best). Scouting for potential sites should follow the guidance discussed above in Table 2. Two important tasks need to be undertaken before ventur-

Table 1. Basic Elements of a Stormwater Retrofitting Implementation Strategy

Step	Elements	Purpose
1	Preliminary Watershed Retrofit Site Inventory	First cut at identifying potential retrofit sites
2	Field Assessment of Potential Retrofit Sites	To verify that sites are feasible and appropriate
3	Prioritizing of Sites for Implementation	To set up a priority for implementing future sites
4	Public Involvement Process	To solicit comments and input from the public and adjacent residents on potential sites
5	Retrofit Design	To prepare construction drawings for specific facilities
6	Permitting	To obtain the necessary approvals and permits for specific facilities
7	Construction Administration and Inspections	To ensure that facilities are constructed properly in accordance with the design plans
8	Maintenance Plan	To ensure that facilities are adequately maintained

Table 2. Locations for Stormwater Retrofits

Location	Type of Retrofit	Case Study
Existing stormwater detention facilities	Usually retrofitted as a wet pond or stormwater wetland capable of multiple storm frequency manaagement	Wheaton Branch, Sligo Creek, Wheaton, MD – multi-cell wet pond with extended detention
Immediately upstream of existing road culverts	Often a wet pond, wetland, or extended detention facility capable of multiple storm frequency management	Epsilon Pond, Redland, MD – dry extended detention facility
Immediately below or adjacent to existing storm drain outfalls	Usually water quality-only practices such as sand filters, vegetative filters or other small storm treatment facilities	Long Quarter Branch, Towson, MD – gravel based wetland filter
Directly within urban drainage and flood control channels	Usually small-scale weirs or other flow attenuation devices to facilitate settling of solids within open channels	Indian Creek, College Park, MD – instream concrete weir flow attenuationi device
Highway rights-of-way and cloverleafs	Can be a variety of practices, but usually ponds or wetlands	Bear Gutter Creek, Route 22, Armonk, NY – combination wet pond and stormwater wetland
Within large open spaces, such as golf courses and parks	Can be a variety of practices, but usually ponds or wetlands capable of multiple storm frequency management	Meisner Ave Retrofit, Staten Island, New York City – micro-pool extended detention facility
Within or adjacent to large parking lots	Usually water quality-only facilities such as sand filters or other organic media filters (e.g., bioretention)	Kettering Subdivision, Prince Georges Co., MD – Bioretention practices

ing into the field. First, the drainage area to each potential retrofit site should be delineated and the potential surface area of the facility measured. The drainage area can be used to compute a capture ratio. Capture ratio is the percentage of the overall watershed that is being managed by all retrofit projects. The surface area is used to compute a preliminary storage volume of the facility. A shortcut storage volume consists of multiplying two-thirds of the facility surface area times an estimated depth ($2/3 \cdot SA \cdot d$). These two values can be used as a quick screening tool. In general, an effective retrofitting strategy must capture at least 50% of the watershed and a minimum target storage volume for watershed retrofit is approximately 1/2 inch per impervious acre within the watershed.

Step 2. Field Verification of Candidate Sites

Candidate retrofit sites from Step 1 are investigated in the field to verify that they are feasible. This field investigation involves a careful assessment of site specific information such as presence of sensitive environmental features, location of existing utilities, type of adjacent land uses, condition of receiving waters, construction and maintenance access opportunities, and most importantly, whether or not a desirable retrofit will actually work in the specified location. Usually a conceptual sketch is prepared and photographs are taken.

One study that incorporated the principles of this process was the Longwell Branch Stream Restoration Study conducted in Westminster, Maryland in 1994. The Longwell Branch watershed drains approximately two square miles of moderate-to-high density commercial and residential land. The area was built prior to stormwater management requirements, and consequently the stream system was suffering the typical urban impacts along much of its reach. This investigation utilized a retrofit inventory form which provided field investigators with specific information such as topography, property lines and ownership, storm drain outfall locations, drainage area, mapped utility locations, and other important site design features. This data helps field investigators decide if sites are to be retained or eliminated from further consideration. Longwell Branch retained approximately two-thirds of the identified sites. Those eliminated involved conflicts with utilities, wetlands or adjacent properties.

Step 3. Prioritize Sites for Implementation

Once sites have been located and determined to be feasible and practical, the next step is to set up a plan for future implementation. Even the best stormwater retrofitting programs have limited capital budgets for individual project design and construction. Therefore, it is prudent to have an implementation strategy based on a prescribed set of objectives. For example, in some watersheds, implementation may be based on a strategy of reducing pollutant loads to receiving waters where the priority of retrofitting might be to go after the “dirtiest” land uses first. But if the strategy is oriented more toward restoring stream channel morphology, priority retrofits are targeted to capture the largest drainage areas and provide the most storage. Whatever the restoration focus, it is useful to provide a scoring system that can be used to rank each retrofit site based on uniform criteria. A typical scoring system might include scores for the following items:

- Pollutant removal capability (storage provided and type of BMP)
- Stream channel protection capability (ability to control modest flow events)
- Cost of facility (design, construction and maintenance)
- Ability to implement the project (land ownership, construction access, permits)
- Potential for public benefit (education, location within a priority watershed, visible amenity, supports other pubic involvement initiatives)
- Percent of watershed capture

Step 4. Public Involvement Process

A successful project must involve the immediate neighbors who will be affected by the changed conditions. Nearly all retrofits require significant modifications to the existing environment. A dry detention pond, for example, is for some a very desirable area in the community. It is a place to walk the dog and only rarely is there any water in the facility. A wet pond or stormwater wetland retrofit, on the other hand, may have large expanses of water and may have highly variable water fluctuations. Adjacent owners sometimes resist these changes. In order to gain citizen acceptance of retrofits, affected persons must be involved in the process from the start and throughout the planning, design and implementation process. Citizens who are informed about the need for, and benefits of, retrofitting are more likely to accept projects.

Still, some citizens and citizen organizations will never support a particular project. This is why it is mandatory that there be an overall planning process which identifies projects early and allows citizen input before costly field surveys and engineering are performed. Projects that cannot satisfy citizen concerns may need to be dropped from further consideration.

This step of a good retrofit program must utilize a good public relations plan. Slide shows, or field trips to existing projects, can be powerful persuasions to skeptical citizens. Before any site goes forward to final design and permitting, it should be presented at least once to the public.

Step 5. Retrofit Design

The design process is for some, including this author, the most rewarding part of the process. Here, the concept is converted from a dream to a construction drawing. Design of retrofit projects incorporates the same elements as any other BMP project including: adequate hydrologic and hydraulic modeling, detailed topographic mapping, property line establishment, site grading, structural design, geotechnical investigations, erosion and sediment control design, construction phasing and staging to name a few. But BMP design for developing residential areas usually follows a prescribed design criteria (e.g., control of the 2-year storm or sizing for a specified water quality volume), whereas retrofit designers must work backwards from a set of existing site constraints to arrive at an acceptable stormwater control.

Sometimes this process yields facilities that are too small or ineffective, and therefore not practical for further consideration. One such project in Gaithersburg, MD, was recently proposed as a major stormwater wetland upstream from an existing road culvert to control a 1,000 acre watershed. The problem was that only 1/20th of an inch of total storage (.05") was obtainable. Clearly this facility would have been a maintenance nightmare and likely would have done little to remove pollutants or control downstream channel erosion. The City of Gaithersburg correctly decided not to pursue the project even though it had already retained a consultant and spent significant time and money on preliminary design.

The key to successful retrofit design is the ability to maximize pollutant removal and channel erosion protection while limiting the impacts to adjacent infrastructure, residents or other properties. Designers must consider issues like avoiding relocations of existing utilities, minimizing impacts on existing wetland and forest, maintaining existing floodplain elevations, complying with dam safety and dam hazard classification criteria, avoiding bad maintenance situations, and providing adequate construction and maintenance access to the site.

Step 6. Permitting

Permitting issues for retrofit projects often involve impacts on wetlands, forests and floodplain alterations. Many of these impacts are either unavoidable or necessary to achieve reasonable storage targets. Permitting agencies are primarily focused on ensuring that the impacts have been minimized to the extent practicable and that the benefits of the proposed project are clearly recognizable.

One recent project in New York City's Staten Island Bluebelt illustrates this point. A larger detention facility is being proposed for the Richmond Creek subwatershed to control a 400-acre headwater drainage area. The facility was initially conceived to provide a wet pond with wetland elements and extended detention of runoff from the 1-year storm. The facility is proposed within the Bluebelt park system where impacts to trees and wetlands were a major concern to park personnel and regulatory agencies.

Several alternative designs were presented that minimized wetland and forest impact while maximizing storage volume to provide downstream channel erosion protection. The real balancing act was to achieve enough storage to provide meaningful downstream channel protection and at the same time minimizing upstream impacts to a mature forest and wetland. The final acceptable solution consisted of a micro-pool wet pond with extended detention for the 1-inch rainfall event and a total disturbance limit of about a half acre.

Step 7. Construction Administration and Inspections

Like any major design project, proper construction inspection and administration is integral to a successful facility. This is especially important for retrofit projects. Retrofitting often involves construction of unique or unusual elements, such as flow splitters, underground sand filters, or stream diversions. These practices are unfamiliar to many contractors. Most publicly funded projects are awarded to the low bidder, who may be qualified to do the work but has never constructed projects of this nature before. Therefore, it is almost a necessity to retain the original retrofit designer or other qualified professional to answer contractor questions, approve shop drawings, conduct regular inspections, hold regular progress meetings, conduct construction testing, and maintain construction records.

Step 8. Maintenance Plan

Always the last element to be discussed, and often the least practiced component of a stormwater management program, maintenance is extremely important in retrofit situations. The reasons are simple. Most retrofits are undersized when compared to their new development counterparts, and space is at a premium in urban areas where many maintenance provisions such as access roads, stockpiling or staging areas are either absent or woefully undersized.

Designers (see Step 5) must balance maintenance access and storage volumes (for forebays, catch basins, and debris trapping areas) with water quality, flood control, and the other constraints discussed above. But in Step 8, the maintenance must be accomplished as designed.

Retrofit Case Studies

1. *Example of Retrofitting an Existing Stormwater Detention Facility Wheaton Branch, Montgomery County, MD*

The Wheaton Branch facility, located near Wheaton, MD, is arguably one of the best known modifications of a former dry detention facility, retrofitted to provide water quality and channel protection controls. The facility, constructed in 1990, drains an 800-acre watershed that is over 50% impervious. A unique design feature was the three-cell wet pond (constructed around an existing sanitary sewer trunk main) to provide water quality controls. Extended detention controls for the 1.5-inch rainfall event were incorporated for channel protection. The three-cell pond has a complex flow path for both baseflows and small stormflows to facilitate maximum settling of solids. Controls for larger storms (i.e., two - 100 year rainfall events) were balanced against upstream backwater constraints and dam safety considerations. Figure 1 illustrates the key operational and design elements of the project.

The first cell of the facility, or forebay provided almost a tenth of an inch of storage per impervious acre within the watershed (this is too small for most retrofits). A 25-foot wide access ramp with a level 30' by 30' pad was provided for future dredging. During the design phase, it was estimated that dredging of the forebay would be necessary every five years or so. The first cleanout of the forebay occurred in July 1997, a little over seven years after completion of the project.

The Wheaton Branch retrofit facility was part of the larger Sligo Creek watershed restoration project. Downstream habitat improvement and native fish restocking projects accompanied the retrofit and have proved very successful over their seven-year initial period. John Galli, (Galli and Schueler, 1992)and his colleague Jim Commins (1992) have published several reports and articles on the success of the stream restoration efforts in Wheaton Branch.

Some important design lessons are also illustrated by the Wheaton project. The existing hydraulic characteristics of the facility were first analyzed to assess the control originally provided. The original facility provided partial control of the 2-, 10-, and 100-year storm and safely passed

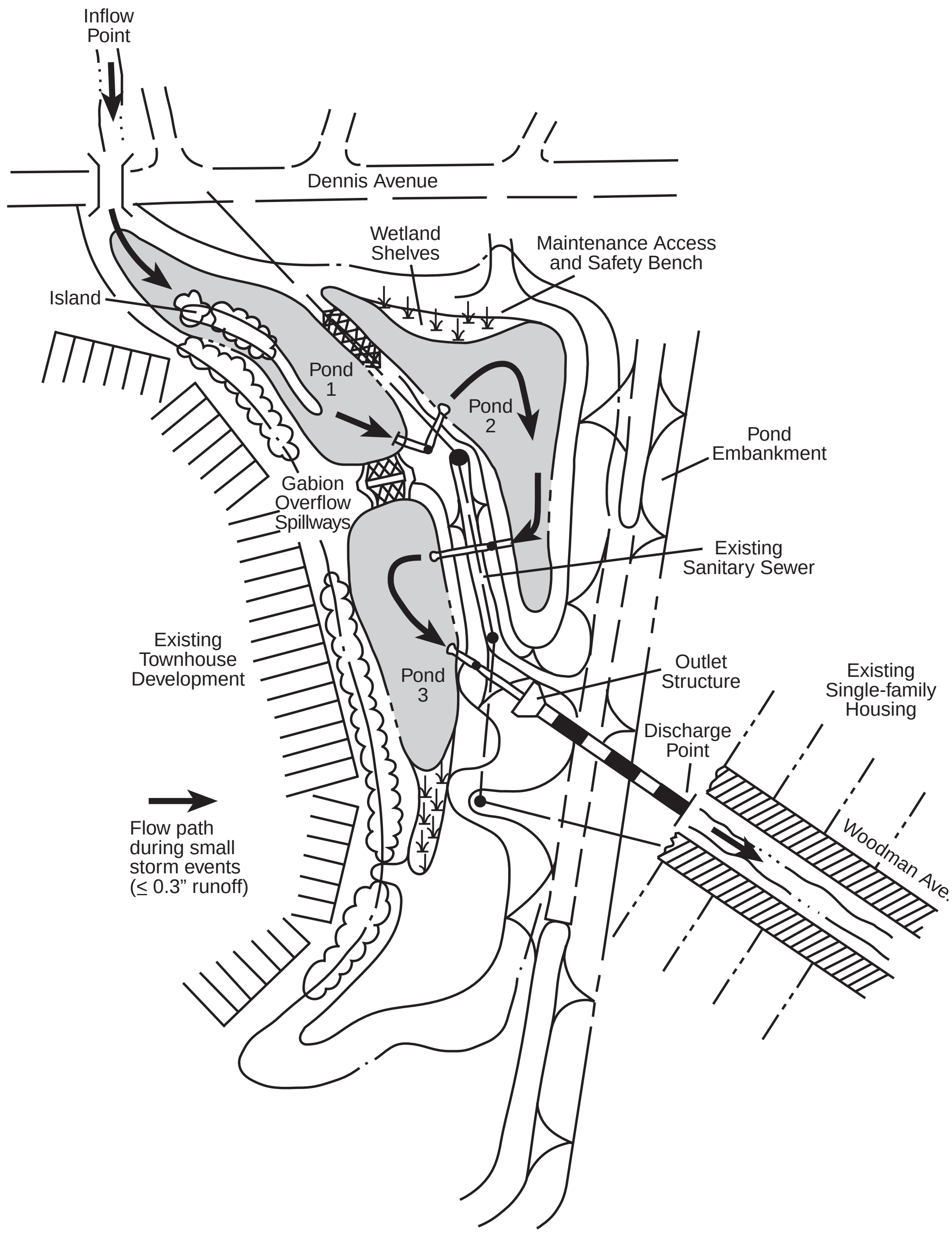

Figure 1. Wheaton Branch Retrofit key operation and design elements – Montgomery County, MD

the probable maximum flood (PMF) through a massive emergency spillway. The retrofit required a balancing act to maximize water quality control, while maintaining enough control for larger storms to avoid impacting downstream houses or the 100-year floodplain.

Routing storms through the three-cell pond was extremely difficult due to the very low head conditions and the unusual backwater created by downstream ponds. The original pond bottom was excavated for much of the permanent pool storage (for pond and wetland components), the emergency spillway was modified to maintain passage of the PMF and the outlet control structure was completely overhauled.

All of these measures added up to quite an expensive project. The total cost for the facility, including engineering, construction, and construction inspection was approximately $800,000. Although this was certainly a healthy sum, it equates to approximately $640,000 per square mile ($1,000/acre) of drainage area. This is a third less than the typically quoted figure of approximately $1 million per square mile of drainage for average retrofitting (Karouna, 1989).

2. *Example of a Retrofit in a Highway Right-of-Way Bear Gutter Creek, Westchester County, NY*

The Bear Gutter Creek Retrofit is one of many projects recently designed to protect the Kensico Reservoir (one of the principal components of New York City's drinking water system) from impacts of stormwater runoff. The Bear Gutter watershed is approximately one square mile in area and drains mixed land uses, having approximately 30% impervious area, directly into the Kensico Reservoir. Note that this is an unfiltered drinking water system serving millions of New Yorkers. The retrofit is located immediately below a state road culvert and within the NY Route 22 right-of-way.

Interesting design features include a flow diversion weir at the downstream end of an existing large diameter road culvert which diverts baseflow and stormflow for up to the 1.5-inch rainfall event into a primary settling area. Storms larger than the 1.5-inch rainfall are diverted to a stabilized downstream channel below the facility. The primary settling chamber is sized for about 1/3-inch per impervious acre and has both a wet component and storm storage above the wet pool. An existing 1-1/2-acre emergent wetland, adjacent to the facility receives runoff as a polishing treatment below the primary settling chamber. See Figure 2 for an illustration of the facility and representation of design features.

The design criteria for the Bear Gutter Creek project (as well as all of the Kensico project) was to provide a facility

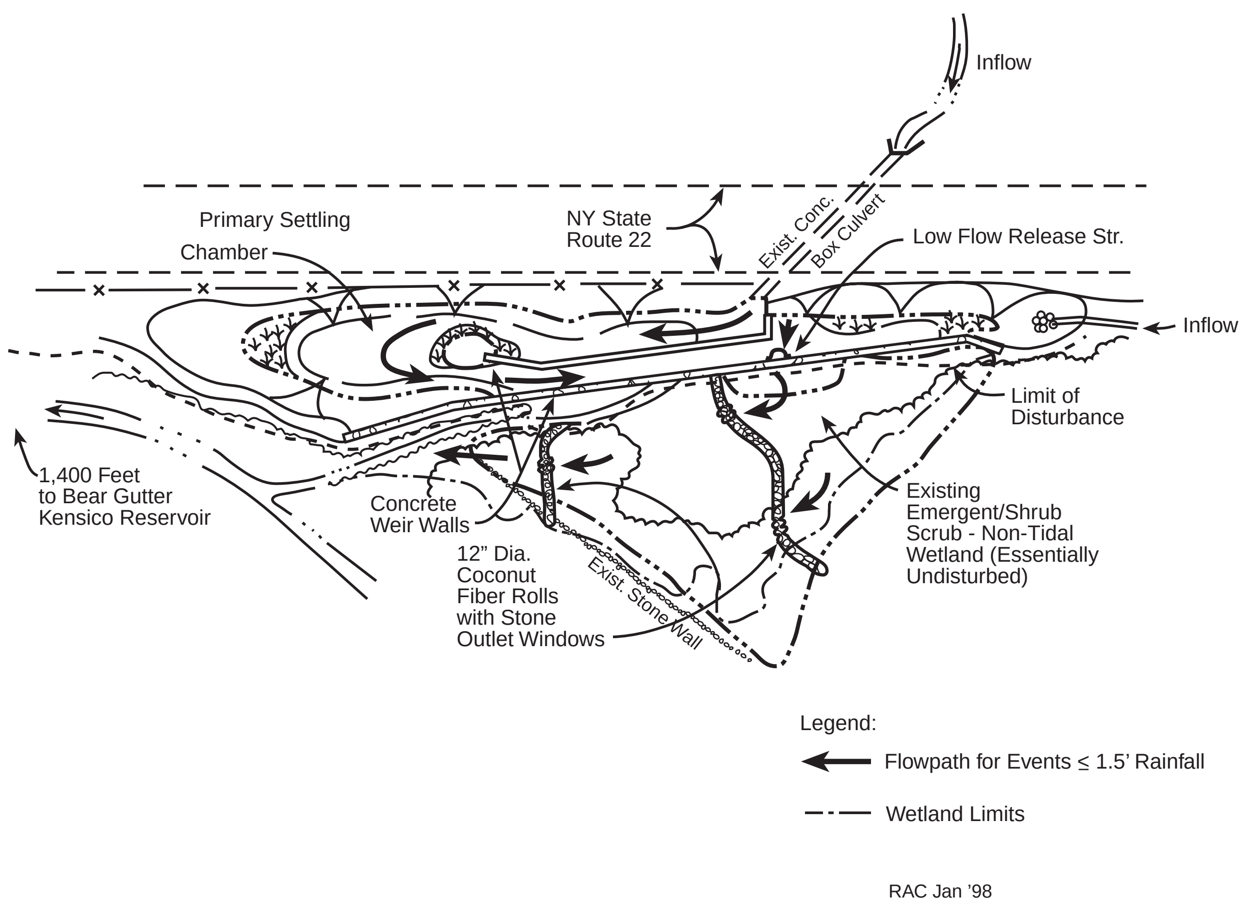

Figure 2. Bear Gutter Creek Retrofit – Illustration and representation of design features

with the minimum storage volume necessary to maximize particulate settling, and provide long detention times to allow for fecal coliform dieoff. An original design concept called for siting the facility in the middle of the 1-1/2 acre wetland. Unfortunately very little space was available within the road right-of-way or anywhere else outside of the existing wetland. The solution was to use a flow diversion structure coupled with a concrete weir and baffle to maximize the length of the flow path within the primary settling chamber and then utilize the wetland as a "polishing" treatment. Coconut rolls were specified within the wetland to encourage additional detention for controls of larger storms.

Summary — Is Retrofitting Really That Complicated?

The answer to this question might seem elusive. Retrofitting can be a daunting task, and usually not an inexpensive one. The key to a successful local program is to follow a systematic and straightforward process toward implementation. The eight-step process presented above is certainly not the only way to get projects built. Some jurisdictions identify and construct pilot projects first and then expand a program from there. Others spend much more time on planning and public involvement. Whatever the focus, retrofitting is still more of an art than a science, and planners and designers who take an approach geared toward innovation will go a long way toward successfully planning, designing, and building stormwater retrofit projects.

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Identifying Wetland Restoration Opportunities in the Rouge River Watershed

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Abstract

This report discusses factors to be considered in identifying wetland restoration opportunities in an urban river watershed. The discussion is based on a recent study of wetland restoration opportunities in the Rouge River Watershed in southeast Michigan, funded by the United States Environmental Protection Agency through the Rouge River National Wet Weather Demonstration Project. Wetland ecosystem restoration or creation in urban settings presents certain unique challenges compared to similar projects in rural or undeveloped areas. Identifying appropriate sites for wetland restoration in urban settings requires special consideration of the unique characteristics of urban environments. Environmental challenges frequently encountered in urban settings include contaminated sources of water, contaminated soils, severe hydrologic conditions, unsuitable adjacent land uses, and severely disrupted plant and animal communities in existing wetlands. Social and economic issues that influence urban wetland restoration projects include opportunities for recreational uses of restored wetlands and environmental education in wetland areas. When wetland restoration projects account for these factors, remarkable wetland ecosystems can be restored in urban areas.

Introduction

Wetland restoration has become a widely used part of many river restoration efforts. Wetland ecosystems provide many functions to a watershed, such as fish and wildlife habitat, water quality improvement, flood water storage, and passive recreation. In an urban environment, these wetland functions have usually been severely impacted over the years so there are benefits to be gained by restoring wetland habitat as part of any river restoration effort.

While restoration of wetland habitat has been an active part of resource management for many years, most wetland restoration efforts have been focused in rural areas as part of wildlife management programs. Organizations such as the US Fish and Wildlife Service, state wildlife departments, and private conservation organizations such as Ducks Unlimited have restored thousands of wetland acres over the years. The techniques for wetland restoration in agricultural environments have been developed over many years and are based on many experimental approaches. The state of the art is such that wetlands can be restored to provide habitat for specific plant and animal communities. Several guidebooks are available for the habitat requirements of certain wildlife species.

Since the 1970s, research has been conducted on the design and construction of wetlands that provide functions other than fish and wildlife habitat. The majority of this research has focused on the use of wetlands for wastewater treatment, but there have also been some notable efforts to design wetlands for the specific purpose of abating nonpoint source pollution. The wastewater treatment field has evolved to the point where design manuals have been published detailing the design and construction of several different types of treatment wetlands. Supplementing these manuals is a series of guidebooks describing design guidelines for stormwater treatment wetlands (Schueler, 1992).

While the information and techniques developed for wetland restoration in wildlife management and nonpoint source pollution treatment is valuable, the application of this information to urban wetland restoration projects needs to be critically evaluated. The urban ecosystem is limited by physical, chemical, and biological characteristics that influence the types of wetland ecosystems that can be practically restored. The urban ecosystem is sufficiently different from undisturbed ecosystems that design manuals need to be modified to reflect the urban environment. The following information is meant to highlight some of the key aspects of the urban ecosystem that should be considered when undertaking wetland restoration projects in urban settings.

Physical and Chemical Factors

Frequency and duration of flooding. The hydrologic character of urban rivers and streams frequently consists of widely varying fluctuations in flow rate and water level and frequent flooding. While wetland habitats are also frequently flooded, the frequency and duration of flooding in an urban setting is usually greater than in undisturbed rivers and needs to be considered. The flooding frequency of certain urban rivers may be severe enough to preclude the establishment of forested wetlands. Forested wetlands in northern areas of the United States require a period of relatively low water levels in order to survive.

The Rouge River is a river ecosystem that is characterized by a diversity of hydrologic conditions with a diversity of frequency and duration of flooding. Some reaches of the river experience flooding out of the river channel an average of eight times a year predominantly in the early spring. Water level fluctuations accompanied by these flood events typically represent a rise in river water level of six feet. Wetland restoration sites that were identified in the Lower Rouge River were all within the floodplain, but at locations where the water level fluctuations were typically less than three feet. The decision to locate wetland restoration sites in areas with moderate flood elevations was made in an effort to reduce the adverse impact of severe frequent flooding on waterfowl nesting success. All of the wetland restoration designs accounted for the frequency and duration of flooding and were designed to allow flood waters to inundate restored wetlands, thus imitating the relationship between riparian wetlands and flooding conditions in the river.

Water level fluctuations. In locating wetland restoration sites, one should consider the magnitude of water level fluctuations. Wetland habitat that is flooded by three to four feet of water may be detrimental by flooding wildlife populations, especially if the flood occurs during the waterfowl nesting season. Water level fluctuations in wetlands have been recognized by wildlife biologists as important aspects of wetland management, and they frequently manage wetlands by draining the basin to encourage plant diversity. The wetland restoration sites in the Rouge River were expected to receive stormwater runoff during periods of precipitation, but the character of the watershed draining into the wetlands was such that the water level in the wetland would not recede between storm events. While permanent open water wetlands are important to certain species of wildlife, the wetland inventory of Wayne County indicated that open water wetlands were relatively common in the vicinity of the wetland restoration site. The design of the wetland restoration was, therefore, intended to produce a wetland that would have moderate water level fluctuations. This was accomplished by designing inlet diversion structures that would divert only a portion of each storm event into the wetland, thus allowing for minor water level fluctuations typical of undisturbed wetlands along the river. Simplified hydrologic models of the water balance for the wetland were used to determine the volume of water to be diverted into the wetland with each storm event.

Flow rate. Wetland restoration projects should minimize the flow rate of water flowing into the wetland because of the damage caused by high velocity to habitat and fish and wildlife populations. Receiving streams in urban settings are frequently subjected to water flowing at high velocity, which causes significant adverse impacts. Wetlands may be significantly impacted in a similar manner unless measures are taken to mitigate the potential impacts. One effective technique that has been used in the Rouge River is to provide a regulated inlet structure that restricts the amount of water that flows into the wetland. Bypass structures are used to protect the wetland from severe velocity and the accompanying damage to fish and wildlife populations.

Water quality. Wetland restoration efforts can be severely constrained in urban efforts unless the water quality of urban runoff is considered. While wetland habitats have been recognized as potential nutrient sinks, wetlands can also be damaged by severe nutrient loading. Several approaches were used to manage the potential adverse impact of excessive nutrient loading. First, the wetland restoration sites in the Rouge River are protected by sedimentation basins prior to the wetland that remove excessive sediment and nutrient loading. The basins were designed with a restricted outlet that allows for floating material and sediment to be retained in the sediment basin. The effect of such sediment basins is to limit sediment load to the wetland and to provide a location where sediment can be removed during routine maintenance and operation. The second approach was to design wetland restoration projects that planned for plant communities adapted to high nutrient loading. In practice this meant that there was a predominance of emergent wetlands and a minimum of open water and submergent wetland types.

Bioaccumulative contaminants. Several recent reports have shown that levels of bioaccumulative contaminants, such as heavy metals, are higher in fish and wildlife in stormwater ponds compared to populations in wetlands not exposed to urban stormwater. The Canadian Wildlife Service and Environment Canada (Wren, et al.,1997) reported that persistent chemicals bioaccumulate in sediments, water, and wildlife and, in some locations, the chemical concentrations exceeded the Ontario Sediment Quality guidelines for low effect level for aquatic animals. The report indicated that definitive estimates of exposure and effects are required to clearly understand the risk to wildlife populations. Similarly, in a study of fish species in stormwater treatment ponds in Florida, (Campbell 1994) reported that red ear sunfish had significantly higher levels of cadmium, nickel, copper, lead, and zinc compared to fish from control ponds. Bluegill and largemouth bass collected from stormwater ponds also had significantly higher levels of heavy metals compared to control ponds.

Wetland restoration projects in the Rouge River accounted for the potential accumulation of contaminants by incorporating several protective measures. Wetland sites with heavy industrial uses in the watershed were avoided. When wetland sites with runoff from commercial areas were selected, sediment basins were designed to trap contaminants bound to sediment particles prior to the runoff entering the wetland. Restored wetland habitats were also designed to minimize the potential for incidental ingestion of contaminated sediment by fish and wildlife species by limiting the area of open water available for fish and waterfowl feeding.

Biological Factors

Target wetland communities. Wetland restoration efforts should be based on the type of wetland habitats that contribute to the restoration of a diverse river ecosystem. In certain river ecosystems, emergent wetland habitats designed to abate nonpoint pollution sources are important, while in other regions it may be more appropriate to restore riparian forests that support wildlife species and stabilize river banks. The type of wetland to be restored should be determined prior to searching for potential sites and should be based on an open review of wetland resources and natural resource restoration goals for the river ecosystem.

Maps of the wetlands of the Rouge River indicated that approximately 70% of the wetlands in the watershed have been lost. The analysis also showed that the most common type of remaining wetland is forested wetland habitat concentrated along the river corridor. A review of vegetation maps of the vegetation prior to European settlement indicated that while forested wetlands were present, there were also extensive areas of emergent wetlands in the watershed. Emergent wetlands are recognized as being effective in abating nonpoint sources of pollution and are important areas for fish and wildlife populations. Based on the historical vegetation data, and the goal to manage nonpoint source pollution of the river, a decision was made to restore emergent wetland habitats to the greatest extent possible.

Existing habitat. Whenever possible wetland restoration sites should be connected or linked to existing wetland habitat. An important benefit of this approach is that plant and wildlife populations in the existing wetlands have an opportunity to migrate into the new wetland habitat. The existing wetlands maps for the Rouge River watershed were used to identify existing habitat along the river corridor. Wetland maps were then compared to maps of hydric soils to indicate the potential for wetland restoration. Each existing wetland was visited and assessed for wildlife use and condition of existing habitat. The result of this analysis of existing wetland habitat and quality was that wetland sites were restored adjacent to forested wetlands that had viable populations of amphibians, reptiles, and waterfowl.

Nuisance plant, fish, and wildlife species. Wetland restoration projects are frequently subjected to significant damage by nuisance plant, fish, and wildlife species. Carp can destroy plantings of submerged and emergent plant species and cause severe turbidity due to feeding activity. The resultant turbidity can suppress development of submerged aquatic plant communities. Grazing of wetland plants by geese can be severe and has in some cases resulted in complete removal of plants in newly planted wetlands. Nuisance plant species include invasive wetland plant species, such as purple loosestrife and reed canary grass, which can dominate a wetland, preventing the development of a diverse plant community. On the Rouge River, carp have been controlled at wetland restoration sites by limiting the connection of the wetland to the river. When it was necessary to connect wetlands to the river, a chain link fence was installed across the connection to the river to exclude adult carp. However, carp were introduced into several restoration sites during a flood and manual methods of control have been necessary. Canadian geese damage has been managed by stringing rope with flags across the wetland at 50-foot intervals until the wetland plant community was established. The ropes seem to disturb geese from landing on the wetland surface thus preventing grazing in the wetland. After the plant community was stabilized, the ropes were removed.

Ecological traps. Ecological traps are areas of attractive habitat that represents an unsafe condition for plant or animal populations (Gates and Geysel, 1978). Species mortality in ecological traps frequently exceeds reproduction due to the hazards represented in the habitat. A stormwater treatment basin with steep side slopes and permanent open water is an example of an ecological trap. Waterfowl nests located within the storage elevation of the retention basin can be destroyed during precipitation events and result in adverse impacts to reproduction of the species. Wetland restoration in urban rivers needs to be planned in such a way that ecological traps are not created.

Ecological traps were prevented in the Rouge River wetland restoration areas by linking the new wetlands to existing habitat that offered an opportunity for a sustainable population of plant and animal species. Buffer areas of natural vegetation were created around all new wetlands to provide upland habitat for wetland species that require upland habitat for part of their life cycles. Wetland restoration sites surrounded by urban or industrial property were avoided. Finally, all restored wetland areas were linked in one manner or another with wildlife corridors to allow migration of wildlife species.

Socioeconomic Factors

Environmental education. Wetland restoration projects represent an opportunity to provide outdoor classrooms to local schools and recreation departments. Natural habitat in urban settings are rare and if a restored wetland area is planned near a school, the opportunity to explore cooperative arrangements with the school may be worthwhile. The wetland restoration sites in the Rouge River have been used by the science classes studying aquatic ecology and soil chemistry, as well as art and creative writing classes. The wetland is located within one mile of the high school and is being used by additional classes and programs each year.

Passive recreation. The emphasis of wetland restoration is the renewal of wetland functions, such as fish and wildlife habitat, water quality protection, or flood water storage. When the opportunity arises, however, significant public benefits can be realized if passive recreation is integrated into the wetland restoration project. In the Rouge River project, we found that wetlands that had a trail or public access site were used by residents in the neighborhood. During monitoring visits, the residents would share with us their experiences in the wetland regarding wildlife observation or water level fluctuations. Signage at future wetland restoration projects will assist residents in understanding the restoration project and the benefits gained from restoring wetlands.

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Taking Root: Sowing and Harvesting the Seeds of Public Involvement and Education

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The Rouge River, a tributary to the Detroit River, in southeast Michigan, has been well documented as a significant source of pollution to the Great Lakes System. The Rouge River Watershed spans approximately 467 square miles involving 48 communities, three counties, and over 1.5 million residents. The eastern portion of the watershed consists of much of the old industrial areas of Detroit and Dearborn. The western and northern portions consist of newer suburban communities and areas under heavy development pressure.

This paper discusses the products, programs, and partnerships used by the Public Involvement team of the Rouge River National Wet Weather Demonstration Project (Rouge Project) to: 1) first increase watershed awareness in Rouge River watershed residents; 2) educate them about the pollution sources to the Rouge River; and then 3) involve them in restoration of the Rouge River by showing them that small changes in their daily activities can help restore the river.

Even before the inception of the Rouge Project four years ago, it was clear that a comprehensive public involvement and education program was necessary to support Rouge River restoration activities. A survey of watershed residents in 1994 determined that, while few people viewed the Rouge River as a viable resource because of its pollution, the majority broadly supported efforts to improve its quality. The survey determined that a grassroots approach coupled with a top down strategy was needed. A public outreach strategy, based on the survey, used the philosophy that communication with Rouge River watershed stakeholders must be continual, consistent, truthful and always two-way.[1]

The strategy identified seven stakeholder groups that must be educated: the general public, local government officials, industry and business, environmental and community groups, the technical community, the media, and schools.

So, for instance, as local officials were being educated about the Rouge River's problems and possible solutions, the Public Involvement team was developing easy-to-read fact sheets, brochures and posters for the general public. At the same time, pilot pollution prevention programs in three watershed neighborhoods and two business areas were developed to fashion a watershed-wide program and fine-tune appropriate messages for the general public and businesses.

It became clear that several themes had to be used to educate watershed residents. First of all, stakeholders had to learn that they lived in a watershed containing 48 communities and parts of three counties. This is a diverse watershed where land uses range from undeveloped land and farms on its western edge to heavily urbanized industrial sections on its eastern boundary. Household incomes are just as diverse: in Bloomfield Hills, in Oakland County, the average household income is $150,001 while Highland Park, in Wayne County, has an average household income of $9,805. Furthermore, stakeholders needed to understand that the pristine, rural tributary in northern Oakland County was part of the same watershed as the brownish, urban river flowing past the massive Ford Rouge Plant complex in Dearborn.

In addition, since many of those surveyed thought the pollution in the Rouge River was from industrial sources, a public education campaign had to explain storm water and non-point source pollution, and their impacts on the Rouge River. Finally, the campaign had to explain to all stakeholders their personal role in Rouge River restoration efforts.

Products

A number of products were created over the past two years to accomplish our goals. They include:

Activity Book: This 12-page booklet was designed for elementary school students. It contains word searches,

[1]For information about Rouge Project products or stategy, contact Josephine A. Powell, Wayne County (Michigan) Department of Environment, Detroit, MI 48226 Telephone: 313-224-3620.

crossword puzzles and connect-the-dot pictures that entertain while delivering a message about non-point source pollution, watershed awareness and personal responsibility. Over 30,000 books have been delivered to area schools through requests from teachers in six targeted areas in the watershed, to schools that participate in the Friends of the Rouge Education Project and to teachers who attend education conferences. In addition, 10,000 Rouge River posters, featuring wildlife that live in or near the river, were distributed to area schools. The books and posters are also used as a handout at watershed fairs and other community events.

Placemats: Restaurants in the watershed were approached about using a Rouge Project placemat that featured a drawing by a fourth-grade student who won a Friends of the Rouge poster contest. The back of the placemat listed Rouge Friendly pollution prevention tips. Close to 50,000 placemats were distributed to watershed restaurants and were enormously popular, according to a survey of restaurant owners. A second placemat, recently developed, features watershed education, and promotes recreational activities in the Rouge River. Over 50,000 placemats have been used by area restaurants with another 50,000 on order. Currently, the Rouge Project is negotiating with a popular fast-food restaurant to feature a Rouge River placemat in its restaurants during Earth Day week in April, 1998.

Theater Advertising: Three public service announcements were developed for a Rouge River awareness campaign that ran on theater movie screens prior to the featured film, for five months. The first one promoted Rouge Rescue, an annual river clean-up event sponsored by the well-respected grassroots organization, Friends of the Rouge; the second featured a Great Blue Heron as an example of wildlife that lives along the Rouge River; and the third featured Rouge Friendly household tips.

Newspaper Insert: A local community newspaper chain agreed to re-visit the Rouge River for a 10-year update to a section it produced in 1986 entitled " Our River: We discovered it; We settled along its banks; We built homes, farms and factories; And slowly, steadily we began to kill it." The update was a 12-page award-winning insert that reached 160,000 households in 12 communities in the Rouge River Watershed. Entitled "Changing Currents," the section documented the positive changes occurring in the Rouge River Watershed; discussed pollution prevention and Rouge-friendly behavior; and included a watershed map that was later reproduced as a poster.

Door Hanger: To augment storm drain stencilled messages organized by Friends of the Rouge, a door hanger in the form of a fish was developed as a leave-behind information piece for neighborhood residents. Text on the door hanger explains storm drain stenciling activities and lists Rouge Friendly home care activities. To date, over 10,000 door hangers have been distributed.

In addition, an ongoing media campaign has been instrumental in educating the public that they live in the Rouge River Watershed; that everyone is part of the pollution problems in the Rouge and can be part of the solution; and that with everyone's help, the Rouge River can be restored.

Programs

Pollution prevention programs were pilot-tested in three watershed neighborhoods and two business areas to fine-tune public information materials and program elements. They are:

The Rouge Friendly Neighborhood Program: This pollution prevention program was piloted in watershed neighborhoods in a number of areas of the watershed to promote education, river stewardship and storm drain stenciling activities. One pilot area, Brightmoor, is a Detroit neighborhood where the Main Rouge flows through a large park that borders the area. This densely populated, urban neighborhood is bisected by a business strip of predominately auto service businesses and has been plagued by illegal dumping and disinvestment. The local neighborhood organization is very active in the annual Rouge Rescue event sponsored by Friends of the Rouge.

Since the inception of the Rouge Friendly Neighborhood Program, the residents organized a business association that holds monthly meetings attended by city officials from the police department, the department of public works and the local neighborhood city hall and officials from the county environmental department. Environmental issues are a standing agenda item at the meetings and several businesses have qualified to be Rouge Friendly Businesses, which will be discussed below. The residents, in conjunction with Friends of the Rouge, hold a spring and fall Rouge Rescues, and in conjunction with the city parks department, received a Rouge Project community grant to remove several log jams from the river, stabilize river banks, plant wildflowers and native grasses and restore nature trails in the park.

In another pilot neighborhood in a more upscale area, residents have adopted a wetlands that adjoins their subdivision, participated in storm drain stenciling activities and promoted Rouge Friendly lawn and garden tips.

The Rouge Friendly Business Program: The Rouge Friendly Business Program is a companion pollution prevention program to the neighborhood program and was modeled after a similar program in Bellevue, Washington. It is aimed at educating small-to-mid-sized businesses to recognize that they can positively impact the Rouge River by making small changes to daily business practices. Since auto-related businesses are very common in the Rouge River Watershed, an automotive services roundtable, made up of representatives of automotive service associations and the local chamber of commerce and a businessman, was convened. The group met for nearly a year to review draft materials, make suggestions about program promotion and help mold the program before it was implemented. In addition, the industry representatives promoted the program in their publications and helped recruit businesses to participate in the program. Currently, there are 20 Rouge Friendly businesses. In addition, a pilot partnership has been formed with the state Environmental Assistance Division and RETAP program to aim a similar effort at the metal finishers industry. Currently in the planning stage is the creation of similar roundtables for food services and the construction services.

Based on what was learned from the neighborhood and business pilots, the Rouge Project public involvement team has fine-tuned its watershed awareness messages and is now promoting them via slogans such as:

- Use your head, you live in a watershed
- Storm drains aren't garbage cans
- When it comes to pollution, every home is waterfront property
- Everyone is part of the problem and needs to be part of the solution
- Simple changes can make big differences

These messages were incorporated into new tools, like magnets and brochures, that were developed in the past several months. A display, created to stress these messages, includes a watershed map and pictures of Rouge Friendly activities and tips. In the past year, the display has been exhibited at 41 watershed events where public involvement staff made contacts with approximately 27,000 people.

Partnerships

In order to give our messages momentum, a Rouge Public Involvement Team was established that has formed numerous partnerships with many stakeholder groups. Those partners include:

- Watershed townships and cities that have begun to use our "Storm Drains" display at their events.
- A resource recovery authority that has coupled its backyard composting/ yard waste reduction messages with Rouge River Watershed water quality information and pollution prevention techniques.
- A newspaper chain that writes about Rouge restoration and awareness activities almost weekly. The newspaper chain also features a Rouge River guest column written monthly by watershed stakeholders.
- Neighborhood organizations that distribute Rouge materials and spearhead stewardship activities for their section of the Rouge.
- Business associations that helped develop Rouge Friendly business materials and then spread the word about Rouge Friendly activities to their membership. Business owners were also instrumental in restoration activities by making Rouge Friendly activities part of their daily business practices.
- Friends of the Rouge, a grassroots organization, that has spread a stewardship message through several programs, many in conjunction with the Rouge Project. The Friends of the Rouge Education Project teaches water quality testing in 100 watershed schools and oversees a student sampling day of the Rouge River every May. Students are encouraged to create displays and videos for a Student Congress later in the month. The organization also sponsors an annual Rouge Rescue clean-up in several watershed communities and has begun to organize a second clean-up in the fall.
- The Rouge River Remedial Action Plan Advisory Council, composed of representatives from local government, business, the general public and non-profit organizations, that helped create a Rouge River Recreational Guide map to be distributed in the spring of 1998. In addition, Rouge Project public involvement staff participate in various subcommittees of the RRAC and facilitate public education efforts of these committees.
- The League of Women Voters which awarded a wetlands education fellowship to a member who is a resident of a Rouge Friendly neighborhood. She has spoken several times locally about the benefits of wetlands and made presentations on behalf of the Rouge Project. League of Women Voters members have also helped distribute Rouge River educational materials.
- The Greening of Detroit which co-sponsored an Arbor Day event with the Rouge Project for 200 elementary school children incorporating a tree planting event with a demonstration of Rouge Friendly tips.
- Oakland Community College, where an environmental studies teacher has made the Rouge River a regular part of her lesson plans. She also has given her students extra credit if they perform volunteer activities relating to Rouge River awareness.

Although quantifying our success has been difficult, we do have a baseline survey that showed that people are committed to doing what they can do to improve the Rouge River and a future survey will evaluate if the awareness of watershed residents has increased since the inception the public involvement activities. In addition, efforts are underway to better record and report information such as areas stenciled, stream miles adopted, the number of Rouge Rescue sites, the number of participating Rouge Education Project schools, and other volunteer efforts and opportunities as a way of measuring success and documenting compliance with the public education requirements of Michigan's voluntary storm water general permit.

Meanwhile, we are heartened by the following:

- The popularity of the Rouge River Activity Book; it has been a big hit at local teachers' conferences as well as in watershed schools.
- The number of personal contacts we've made at area community events.

- The popularity of the two Rouge River placemats with restaurant owners and their customers.

- The interest of local elected officials and municipal employees who ask for their own copy of our display, and their willingness to distribute Rouge materials.

- The use of our ideas and products by other watershed groups nationwide.

- The increased use of the Rouge River for recreational purposes as people learn of its potential.

Research Findings, Recommendations and Lessons Learned

Listed below are various recommendations that the Rouge Project public involvement team would encourage others to consider when developing public education and involvement materials or programs. These recommendations are based on the research findings or advice received from others, including a Watershed Management Peer Review.

- To effectively inform and involve watershed residents, four central themes should be kept in mind: (1) establishing and maintaining a two-way flow of information with key stakeholder groups; (2) establishing or expanding educational mechanisms aimed at children; (3) building partnerships and utilizing communication networks and resources of existing organizations; and (4) devising ways to use the various public media to best advantage.

- Utilize third parties. As much as possible, try to have information come from sources such as non-governmental organizations or environmental groups, the state environmental regulatory agency, EPA, and recognized experts from the academic/scientific community.

- Peer-to-Peer communication/education is also vital. People respond positively to suggested, behavioral changes if they are being promoted by individuals whom they know and trust or regard as their peers.

- Balance public information materials with public involvement programs. Merely providing information is not sufficient. Programs and activities must be devised and implemented that actually involve citizens and other stakeholder groups in restoration efforts.

- Recognize and appreciate that each target audience, or stakeholder group, will need to be taken through a "communications continuum" of Awareness, Understanding, Involvement and Action.

- Scale is important. To the extent practicable, efforts should be directed to the local level. Implementing education and involvement programs at the right scale and bringing together stakeholders who share a common resource is critical to the success of public education programs. The slogan "Think Globally, Act Locally" surely applies.

- Avoid artificial barriers. Involvement opportunities (particularly in the early stages) should not be limited to only a few activities. To the extent practicable, individuals should be able to choose among a menu of activities or involvement opportunities; and within any given involvement program, flexibility should be offered to allow adaptation to local conditions and personal preferences.

- Lead/educate by example. Educational efforts should not be limited to the general public or community stakeholder groups. Local government agencies must recognize the impact that their own municipal operations have on pollution prevention. Internal staff awareness and education programs should be developed in the areas of equipment and vehicle maintenance, golf course and public lands maintenance, facilities maintenance, and land use planning, to name a few.

- Keep it fun and celebrate small successes. Remember, change doesn't happen overnight: it happens in bits and pieces.

The Tollgate Wetland's Educational Experience

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The Tollgate Drainage District Sewer Separation Project (TDDSP) involves a watershed of 234 acres, 550 residential homes, ten commercial properties, over 500 apartment units, and four governmental agencies. The Project involved the separation of a combined sewer system, and creation of a wetland detention basin. In addition to its stormwater detention uses, the wetland serves as a wildlife refuge, learning center, and, a local point of public outreach to bring the community together.

Introduction

Community organizers have long proclaimed the benefit of involving stakeholders in all projects in order to ensure their success. Residents of the Tollgate Drainage District/watershed were incorporated early in the 'planning process. Methods by which they were incorporated varied. Guiding principles for educating residents and encouraging their involvement were that 1) an investment in attitude and behavior change is a good investment, and 2) retrofitting water resource protection into urban environments will be more successful when accompanied by education and public outreach.

This project included a concept development and planning phase which suggested 1) the implementation of an education and public outreach program during project construction, and 2) the establishment of a long-term assessment and maintenance phase. During the planning process, public outreach was accomplished mainly through mailings and public meetings These meetings minimized negative feelings among the stakeholders.

Conflicts existed between the City of Lansing (Michigan) and Lansing Township due to the City's mandate that the Township separate the stormwater and sanitary water, as part of the City's sewer separation project. The traditional method for disposing of stormwater would be to take it to the nearest river. This cost was estimated and determined to be excessive, and likely to put the Township in financial difficulty. But once the City struck an agreement with the Township to take their sanitary sewer water, the Township had to develop some outlet for their stormwater.

TDDSSP employed an unusual method of dealing with the stormwater. Rather than piping it to the river, the water was retained in the neighborhood and a wetland complex was designed to treat the water on site. This method cost approximately one-third of the traditional method of disposing of stormwater, a savings of $15 million or more.

However, this solution would work only if the residents, or "owners" of the project, and primary stakeholders, changed their social behavior to reduce pollution loading, and act as owners of the wetland complex. In order to bring about changes in behaviors, the residents were given information about how their actions affected the outcomes of the stormwater management system and its costs.

For purposes of the remainder of this paper, the outreach/education approach is divided into two phases. The first is "during construction," or short-term, and the second is "after construction," or long-term. Figure 1 shows the relationship between education/public outreach and construction, and accomodates its impact on the project during the process, and on long-term assessment and maintenance.

Goals of Education and Public Outreach

The public outreach and education goals "during construction" were two-fold. The first was to facilitate commu-

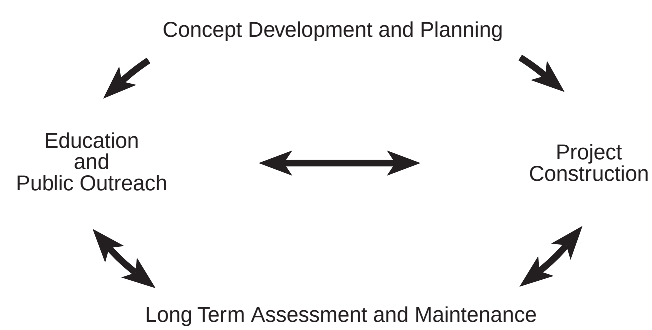

Figure 1. Diagram of Tollgate Drain Project.

nity participation and ownership of the multi-objective project. The second was to change attitudes about the project. To achieve these goals, it was necessary to study the demographics of the resident population, and to learn about their attitudes toward portions of the project.

Three surveys were designed. The first survey indicated long-term residency, conservative beliefs and distrust of public officials. Residents also expressed opposition to change, and did not consider themselves to be environmentalists. It was also learned that their knowledge of environmental issues was limited. For example, when asked if they knew what non-point source pollution is, only 17% of respondents said yes (Figure 2). The survey also indicated that over 65% of respondents fertilized their lawns with a regular program, and half of those were applied by professional lawn care companies. Our baseline data, collected via water quality tests performed prior to construction, showed excessive amounts of fertilizer in the stormwater.

We concluded that public outreach had to be conducted, for both short and long-term outcomes, to bring about attitude change and a stronger sense of environmental stewardship. A number of approaches were employed to make this happen.

Education and Public Outreach During Construction

Public meetings were organized during both the planning and construction processes. These meetings served two main purposes. They assisted in informing the residents about the oncoming project, and they gave stakeholders an opportunity to vent their anxieties.

A neighborhood network was established to bring the community together. The Tollgate District was divided into 11 different sections, and block captains were chosen. Block captains formed phone trees which were utilized to disseminate updates on construction activity, organize neighborhood meetings and block parties. These meetings and block parties were used as forums to educate residents.

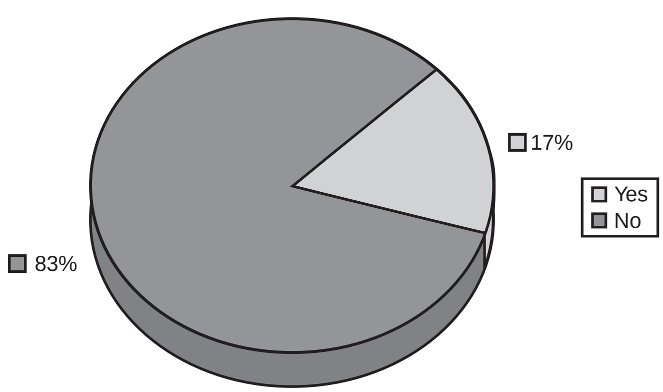

Figure 2. Tollgate survey response to the question, "Do you know what non-point source pollution is?"

An on-site office was opened in an apartment in the neighborhood. It was staffed with field inspectors; a hotline was established, and information was distributed from it. Two recent college graduates were hired to work there. They "leafleted" the neighborhood each week, with updates on street closures, paving schedules, and other current project information. They became a positive project presence and were available to residents to assist in aspects of daily living that were impaired by the construction, and answered questions as they arose.

Tours were offered to residents, at their convenience, and explanations were offered. Twenty-four hour responses were available for all problems during the construction phase.

The cost of this during construction outreach was a fraction of the total project. This up-front investment in outreach achieved our goals in a cost-effective manner, as Figure 3 explains.

Besides the pre-construction survey already mentioned, surveys were also done "during construction" and "after construction". The first survey was conducted door-to-door and of the possible 554 single-family homeowner respondents, 549 completed the survey of demographics, behaviors and attitudes. The second and third surveys also concentrated on attitudes and behaviors. Attitudes toward the project changed from 35% positive before construction began to 81% positive after construction was completed.

The public outreach will continue, long term, and will contain several component parts. First, further surveying will be conducted. Surveys will determine the success of public outreach in changing social behaviors and attitudes.

Second, water quality testing will occur on a regular schedule over the next seven years. Should public outreach be successful, there should be a reduction in pollution loading. Stormwater quality should improve, as attitudes and behaviors change. Data recovered from water monitoring will become part of a feedback loop designed to provide information and education about successes and failures.

Third, staff members of the drain commission have been trained in all aspects of this project, and are prepared to respond to stakeholders in ways that encourage continued partnership in the project. Maintenance needs of the wetlands and the storm/sewer system should decline as behaviors change. Should behaviors toward pollution loading not change, maintenance costs will ascend, which we do not want to happen.

Fourth, education will be ongoing and will not be limited to this watershed. It will include a variety of participants and programs. Partnerships have been formed with local environmental groups such as Urban Options, which has

• Staffing	$27,000
• Field Office	$2400
• Supplies	$1000
• Hotline	$300
Total	$30,700

Less than 1/3 of 1% of the Total Project Budget

Figure 3. Education and public outreach investment (during construction).

agreed to 1) send representatives to neighborhood block parties and teach composting techniques, 2) work with local landscapers to demonstrate environmentally friendly landscaping, and 3) provide direct technical assistance to residents. Local grade schools and other educational institutions have been contacted and teams have been established to develop curriculum items on urban non-point source pollution issues such as wetland and stormwater management, pollution reduction, and ecosystem diversity. The Tollgate wetlands will become a living classroom for field trips for students of all ages.

A reptile and amphibian roundup will take place this spring. Specimens of varying reptiles and amphibians will be caught, tagged, and released in the Tollgate wetlands by second and fifth grade classes from a nearby grade school. This exercise is but one example of programs designed to involve parents and children in understanding the complexities and needs of urban wetlands, and the creatures that live therein.

Other local environmental groups are participating by building birdhouses and educational kiosks along the pathway adjacent to the wetlands, and providing information to assist in educating wetland users from the broader community. Service clubs will be invited for box lunch tours. This broader outreach will have an impact on the attitudes toward the overall sewer separation project in the City of Lansing.

Conclusion

Planning for this project included a public outreach and education plan. The savings to the overall project's initial and long-term costs were substantial. We developed a well-informed public who are willing to take ownership and who understand the need to change behaviors. Retrofitting established urban environments will be more successful when accompanied by education and public outreach. The ultimate success or failure of most projects depends on the willingness of the residents to change their long-standing practices pertaining to wetlands and runoff.

Minneapolis Chain of Lakes Phosphorus Reduction Strategy

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Abstract

The Minneapolis Chain of Lakes is a group of five heavily used urban lakes located approximately 1.5 miles southwest of downtown Minneapolis, MN. The 8,000-acre watershed was developed over the last 100 years and is now completely urbanized. Watershed development and human activities have lead to water quality degradation over the last 40 years. In 1991, a diagnostic study of urban runoff and lake water quality lead to the development of an 8-year, multi-million dollar watershed management effort. A key component of the management strategy was quantification of phosphorus load reduction goals. The watershed management plan is based on reductions of inflow phosphorus loads to the lakes to attain long-term water quality goals. The phosphorus load reduction strategies were developed for each of the lakes based on lake water quality modeling and watershed load analysis. The load reduction goals established for each of the lakes are (percent of total watershed load): Brownie - 10%; Cedar - 40%; Lake of the Isles - 20%; Calhoun - 30%; and Harriet - 20%. The two main structural best management practices (BMPs) being implemented are wetland/pond systems and grit chambers. The structural BMPs, in conjunction with increased street sweeping and public education, are being implemented to reduce phosphorus loading from this fully developed watershed.

The Minneapolis Chain of Lakes are located 3 miles southwest of downtown Minneapolis, MN. The Chain's five lakes are the central natural resource feature of the Minneapolis Chain of Lakes Regional Park. The regional park receives over 2.25 million visitors per year, making it the second most heavily used regional park in the Twin Cities Metropolitan Area. The chain receives urban runoff from a fully developed 8,000-acre watershed that includes portions of Minneapolis and the adjoining suburban communities of St. Louis Park and Edina. Major land use categories presently include residential development (51%), industrial/commercial (19%), and open space (14%). The lakes in the Chain (Brownie, Cedar, Isles, Calhoun and Harriet) are interconnected with navigable channels, culverts or pumping systems. The lakes and the watershed drain from north to south, flowing from the upper chain (Brownie to Calhoun), where water is pumped to Harriet, which discharges to Minnehaha Creek, a tributary to the Mississippi River. Demand for this study and watershed management effort arose from public concerns over increased recreational use of the lakes and attendant deterioration in water quality.

Diagnostic Study

The first step in designing the watershed diagnostic program was an assessment of previous watershed runoff studies. Sixteen subwatersheds were selected for stormwater runoff monitoring in 1991. The selected subwatersheds accounted for 86.8% of the runoff from the watershed. Seventy-three percent of the residential area and 21% of the commercial area in the watershed were included in the monitored areas. Two subwatersheds, the Bass and Twin Lake drainage areas, drain through wetland complexes prior to discharge to the lakes. These subwatersheds were combined with other sample sites for continuous runoff monitoring.

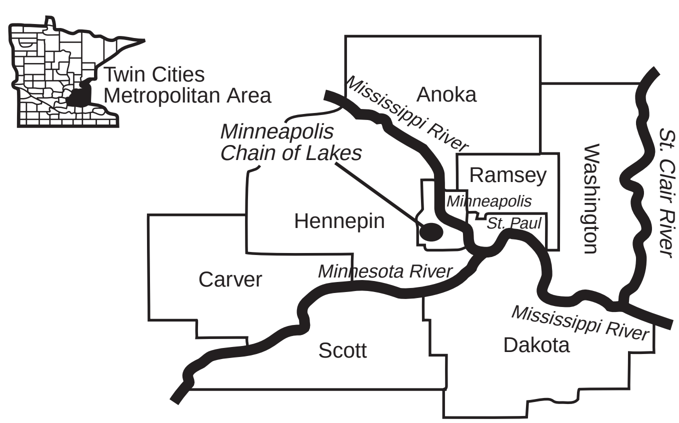

Figure 1. Chain of Lakes watershed location map (after Osgood, 1998)

Minneapolis Chain of Lakes watershed concentration ranges for nutrients were similar to those of the Nationwide Urban Runoff Program (NURP) (Oberts, 1983). Export rates developed from this study were typically below those found in other studies (Wilson and Brezonik, 1998). The stormwater runoff characteristics of importance are listed below:

- The range of pollutant concentrations were consistent with concentrations found in the NURP studies.
- The mass of phosphorus and nitrogen input into the Chain of Lakes from stormwater in 1991 was high enough to cause water quality degradation.
- Most of the measured pollutants exhibit some type of seasonal trend, with most concentrations highest in the spring of the year following snow melt.
- Most of the measured pollutants do not show any major trends among watersheds.
- The heavy metal concentrations in stormwater, while at times quite high, rarely exceed state water quality standards. Relatively low heavy metal concentrations reflect the primarily residential nature of the Chain of Lakes watershed (Wilson, 1993).

Data collected during a 1991 diagnostic study indicated that the lakes exhibit physical and chemical processes indicative of moderately eutrophic lakes, including hypolimnetic oxygen depletion, anoxic sediment phosphorus release, and late-summer decline in water transparency. Based on a variety of trophic indicators, Jensen and Brezonik (1998) concluded that Lake Calhoun, Lake of the Isles, and Cedar Lake are eutrophic and that Lake Harriet is mesotrophic. The water quality studies also examined historical water quality data and the results of paleolimnological studies; this data indicated that water quality in the lakes has significantly declined since the early 1900s, but has been relatively constant since the early 1970s. The lakes seem to have attained a degree of equilibria with watershed nutrient inputs (Brugam and Speziale, 1983; Lee, 1993).

Vollenweider (1976) examined lake eutrophication with regard to areal based watershed loadings of phosphorus and the impact upon the trophic status of a lake with regard to lake mean depth, surface area (and, as such, volume) and flushing rates. Loading levels which exceed Vollenweider's permissible level would lead to increases in lake productivity and accelerated eutrophication. Based on the 1991 loading levels, Lake Harriet's loadings are only slightly above the permissible level. Loadings to Lake of the Isles exceed the permissible level by a factor of 9.3, Cedar Lake exceeds permissible levels by a factor of 5.1, and Lake Calhoun exceeds the permissible level by a factor of 3.8. Lake of the Isles had the highest average phosphorus concentration over the 1991 - 1996 growing season, followed by Lake Calhoun, Cedar Lake, and Lake Harriet (Jontz and Lee, 1998).

Watershed Management Plan Development

Phosphorus and, to a lesser extent, nitrogen, are important in the eutrophication process in lakes. Excessive inputs of phosphorus to lakes will lead to an increase in fertility and subsequent algal blooms. Findings of the 1991 Storm Water Runoff study reinforced these concerns and were useful in designing a watershed management plan. Barr Engineering Company (1992) and Lee (1993) used computer models to calculate the pollutant concentrations associated with particular land uses within the Chain of Lakes watershed. Those concentrations became the basis for determining the estimated total annual mass of pollutants (loadings) contributed to the lakes.

Loading Rates (kilogram/hectare of land/year)

	Total Phosphorus	Total Nitrogen
Open/Green Space Land Use	0.13	1.59
Residential Land Use	0.54	2.52
Comm/Mixed Use	0.41	2.61

Storm event data was reduced using FLUX (Walker 1986), an interactive computer program that calculates pollutant load and flow weighted mean concentrations (FWMC). FLUX was used with the continuous flow records and parameter concentrations to develop a FWMC and loading (in kg/yr) for sites where both flow and sample analysis data were available. Annual event mean concentration and literature values were also used to refine FWMC and load for the monitored and unmonitored watersheds (Oberts, 1983; Oberts, 1990; Bannerman, et al., 1983).

In 1991, stormwater contributed 50% of the Lake Harriet phosphorus budget, and the pumped discharge from Lake Calhoun provided another 21%. Stormwater loadings accounted for over 80% of the phosphorus input to the upper Chain of Lakes. The total mass of phosphorus and nitrogen input to the Chain of Lakes from stormwater in 1991 was much lower than would be expected based on published nutrient yields from other urban watersheds (Mulcahy, 1989).

Table 1. Observed and Modeled Lake Water Quality Conditions for 1991-1995 and Watershed Phosphorus Loads for 1991 from BATHTUB

Five-year Mean Annual Conditions

Lake		Cedar	Isles	Calhoun
Load Source (kg phosphorus/yr)				
Precipitation		38.5	23.4	95.5
External load		220.3	167.8	536.1
Internal load		76	34.3	465
Other[1]		9.6	66.5	112.3
	Total (kg/yr)	344.4	292	1208.9
In-Lake Water Quality[2]				
Observed	Total P (µg/L)	49	59	40

[1] Advective/diffuse inflows

[2] Observed based upon 1991-1995 average lake conditions and 1991 monitored loadings

continued

Table 1. Continued

Predicted Water Quality (BATHTUB model outputs)

Lake		Cedar	Isles	Calhoun
Load Source (kg phosphorus/yr)				
Precipitation		38.5	23.4	95.5
External load		220.3	167.8	536.1
Internal load		76	34.3	465
Other[1]		9.6	66.5	112.3
	Total (kg/yr)	344.4	292	1208.9
In-Lake Water Quality[3]				
Predicted	Total P (µg/L)	33.8	51.1	33.2

[3] Predicted water quality based upon BATHTUB model outputs. Observed TP concentrations greater than predicted concentrations indicates internal phosphorus loading.

Water budget and nutrient concentrations from the storm water sampling were input to the BATHTUB lake model to determine lake interactions. BATHTUB is a lake model designed to facilitate the application of eutrophication models to lakes and reservoirs (Walker 1986). BATHTUB does nutrient and water balance calculations, and predicts water quality conditions using empirical relationships developed by Walker (1985). The model also provides a breakdown, by subwatershed, of nutrient loads to each lake. The BATHTUB model provides diagnostic variables that summarize the physical, chemical, and biological interactions occurring in the lake. These assessments were used to evaluate the management options for each of the lakes.

A critical part of the management plan was the development of lake water quality goals and watershed loading reduction strategies by a Citizens Advisory Committee (Lee, 1995; Derby and Lee, 1998). The long-term goals recommended by the committee are based on an analysis of historical, existing and predicted lake conditions. The goals represent water quality conditions that are close to predicted historical levels and are attainable by reducing watershed phosphorous loads (Heiskary and Walker, 1988; Wilson and Walker, 1989). The short-term goals represent immediate lake improvements, attainable through watershed management and inlake manipulations, while the long-term goals require the lakes to equilibrate with reduced watershed loads.

The long-term (5-10 year) water quality goals, historic water quality, and 1992 average conditions for each lake are:

Lake	Predicted Historical Total Phosphorous*	1992 Summer Mean Total Phosphorous	Long-term Mean TP Water Quality Goal
Brownie**	24	34	35
Cedar	21	48	25
Lake of the Isles	28	74	40
Calhoun	18	54	25
Harriet	19	44	20

* Predicted historical phosphorus derived from Vighi and Chiaudani (1985) which uses lake water chemistry, specifically alkalinity, to predict unimpacted water quality.

** Brownie Lake conditions based upon 1991 data.

In the Chain of Lakes, as in many lake systems, phosphorus is the limiting nutrient. Reducing watershed loadings of phosphorus and interrupting internal phosphorus recycling will reduce blue-green algae numbers and decrease the frequency of nuisance algal blooms. Thus, the watershed management plan is based on reducing phosphorus loads. Phosphorus load reduction strategies were developed for each of the lakes, based on lake water quality modeling and watershed load analysis. The load reduction goals (as percent of total watershed load) established for each of the lakes are as follows:

Lake	Phosphorus Load Reduction
Brownie	10%
Cedar	40%
Lake of the Isles	20%
Calhoun	30%
Harriet	20%

Implementation of Best Management Practices

Priority management areas were chosen based on the results of the 1991 Storm Water Monitoring Program and subsequent modeling efforts. Due to the primary concern for lake eutrophication problems, phosphorus loads were used to determine priority watersheds. The priority watershed management areas were ranked, based upon annual phosphorus load.

The best management practice selection process included a series of analyses that factored in a range of watershed and BMP characteristics. The pollutant of concern (phosphorus) dictated the main emphasis of the selection process. In many cases, the watershed characteristics of each subwatershed area, as well as site availability and characteristics of each site, limited the size and type of BMP. For larger pond/wetland systems, the BMP space requirements were such that large areas of open space were needed; in all cases, these were parklands. Consideration for adjoining neighborhoods and environments/parks required that all BMPs be designed to aesthetically blend in and become a neighborhood asset rather than a “mosquito infested swamp,” as many opponents feared. The cost of BMP installation, and amortized costs on the basis of pollutant removal efficiency over the life of the project, were also factored into each BMP decision. Finally, the maintenance effort for each BMP over the long term dictated which agency would be responsible for long-term management.

As a result of the BMP selection process, the following watershed best management practices were selected as part of the watershed management plan:

<u>Non-structural BMPs</u>

- Water Quality Education
- Catch Basin Stenciling
- Lawn Care Education

- Street Sweeping/Cleaning
- Goose Population Management
- Erosion Control Ordinance

Structural BMPs

- Grit Chamber Construction
- Stormwater Wetland/Detention Basin Construction

The Minneapolis Chain of Lakes Clean Water Partnership Implementation Project began in 1994. Implementation of watershed management practices was through the cooperative efforts of the Minneapolis Park & Recreation Board, the cities of Minneapolis and St. Louis Park, the Minnehaha Creek Watershed District, and the Minnesota Pollution control Agency. As first steps, regenerative air street sweepers were purchased and a watershed-wide education program was implemented. The Minneapolis City Council enacted and implemented a construction erosion control ordinance for all construction activities in 1996. Construction of structural BMPs in the Chain of Lakes watershed began in 1995. Total projected project costs for the seven year program are detailed in Table 2.

In-lake management techniques were also implemented as part of the comprehensive management effort. Prior to finalizing the management plan, the in-lake management alternatives were subjected to the analysis suggested by Cooke, et al., (1993). As part of the comprehensive management plan, whole-lake alum treatments have been completed (Cedar and Isles) or are scheduled (Calhoun) for the lakes. The plan also includes annual aquatic macrophyte harvesting.

Structural Best Management Practices

Priority subwatersheds were targeted for BMP installation. The structural BMPs, in conjunction with increased street sweeping and public education, are being implemented to reduce phosphorus loading. Grit chambers and constructed wetland/detention basins will be responsible for the largest reductions in watershed phosphorus loads to the lakes.

Table 2. Minneapolis Chain of Lakes - Clean Water Partnership Implementation Project Costs for 1994 - 2001 (after Panzer, 1998)

Expenditures		Cost
Education		$374,500
Watershed Management Practices		
Grit chambers	757,580	
Street cleaning	926,500	
Stormwater ponds & wetlands	4,594,500	
Other	7,500	$6,286,080
In-Lake Improvements		
Alum	237,950	
Erosion protection	284,890	$522,840
Monitoring Programs		
Lakes	465,000	
Storm water	433,740	
Beach	37,490	$36,230
Total Expenditures		$8,119,650

Grit Chambers installed within the existing storm sewers settle sediment from storm water. Grit chambers have been or will be constructed in the storm water drainage systems of priority subwatersheds that do not have sufficient open space for detention basins or wetlands. The efficiency of sedimentation (and corresponding pollutant) removal is directly related to the size of the structure — the larger the structure the greater the pollutant removal. Stormwater runoff was modeled using the P-8 model to predict the pollutant removal by grit chambers for flows expected during a typical wet year, dry year, and normal year (HDR Engineering, 1992). The results of this modeling were:

Total Suspended Solids	3% to 58% removal
Total Phosphorus	1% to 26% removal
Lead	2% to 56% removal
COD	1% to 35% removal

The range in pollutant removal reflects the range of sizes of grit chambers modeled (10 different sizes). The highest removals were achieved for a small subwatershed which was 100% impervious. The systems are designed for a 10-year storm (2.29 inches/hour) with a target reduction of 33 - 42% for total suspended solids (Asgain, 1994).

The greatest pollutant loading occurs during late winter snow melt and early spring rainfall. Therefore, it is recommended that these structures be cleaned two times per year: (1) in the fall or winter, in order to have maximum capacity for settling solids in the snowmelt and (2) in the spring, in order to clean solids accumulated from the snowmelt and to maximize capacity for the remainder of the year.

The major BMP expenditures for the Chain of Lakes watershed management effort have been constructed wetlands/detention basins. The priority subwatershed analysis results showed that most of the phosphorus entering Cedar Lake came from the subwatershed draining through Twin Lakes. Twin Lakes (a shallow wetland) receives runoff from about 1,600 acres of residential and commercial land, discharging over half of Cedar Lake's water and over 60% of the external phosphorus load. The area treated by this project represents about 85% of Cedar Lake's contributing subwatershed.

A 1994 feasibility study evaluated several BMP alternatives and selected a combination of measures to address non-point source pollution:

1. Construction of a wet detention pond/wetland in Twin Lakes Park to treat runoff from approximately 1,600 acres before entering Twin Lakes.

2. Excavation of the Twin Lakes basin to improve the lake's aesthetic quality and increase phosphorus removal effectiveness (before discharge to Cedar Lake).

3. Construction of a wet detention pond and shallow wetland on property owned by Minneapolis Park & Recreation Board, immediately upstream from Cedar Lake. This would further treat the discharge from Twin Lakes and the direct runoff diverted from Cedar Lake (Panzer, 1998).

Modeling results for the Cedar Meadows/Twin Lakes watershed detention project indicated that the system would remove 43% of the Cedar Lake watershed phosphorus load. Work on the Cedar Lake watershed project was completed in the spring of 1996.

A similar wet detention pond system is proposed for Lake Calhoun in 1998. The project is currently in the final design phase. The Lake Calhoun detention system will treat runoff from an 897-acre subwatershed draining from the southwest. This subwatershed currently contributes 37% of the total phosphorus load to Lake Calhoun. Modeling for the southwest Lake Calhoun subwatershed detention system indicates that the system would remove 48% of the subwatershed phosphorus load and 13% of total Lake Calhoun watershed phosphorus load.

Conclusions

The use of a wide array of tools made possible the development of realistic and attainable water quality goals for the Chain of Lakes. The realities of urban limnology, that is, the magnitude of stresses placed on the aquatic resources, require that new, alternative BMP strategies be developed. In fully developed watersheds such as the Minneapolis Chain of Lakes, retrofit opportunities have necessitated the conversion of open space (usually parkland) to detention systems. This conversion requires that aesthetic and neighborhood considerations play a major role in the design process.

The practice of urban limnology requires the adaptation of ecological concepts and modeling tools to describe and predict stresses placed on urban lakes. Monitoring and modeling efforts prior to implementing the watershed management plan informed goal setting and allowed for prediction of water quality improvements due to management practices. It is widely understood that BMPs alone will not prevent lake water quality degradation due to watershed urbanization. In the case of the Chain of Lakes, historical data showed that most of the stresses occurred during watershed development. The lakes have reached a new equilibria with current watershed loadings, such that reductions in external and internal phosphorus loads can be expected to cause measurable improvements in water quality. Thus, while BMPs cannot be expected to prevent declines, implementation of watershed practices after lakes have reached this new equilibria can be expected to lead to improvements when implemented in conjunction with in-lake management.

The benefit derived from attaining these goals is improved lake trophic status, which will lead to a reduction in algae blooms and aesthetically improved lake conditions. Attainment of the goals will shift Lakes Calhoun and Cedar from their present eutrophic conditions to slightly mesotrophic states, while keeping Lake Harriet mesotrophic. Lake Calhoun and Cedar Lake present the best opportunities for water quality improvement through implementation of watershed management practices. Monitoring results suggest that shifts in water quality are already occuring (see Figure 2).

Lake monitoring results for 1996-97 show that Cedar Lake and Lake of the Isles water quality is now approaching the lakes' goals (see Table 3). The 1993-97 period included years of higher than average precipitation and some of the water quality improvements noted may be due to increased lake flushing. Monitoring over the next 3 years will further indicate the stability of water quality changes due to watershed management.

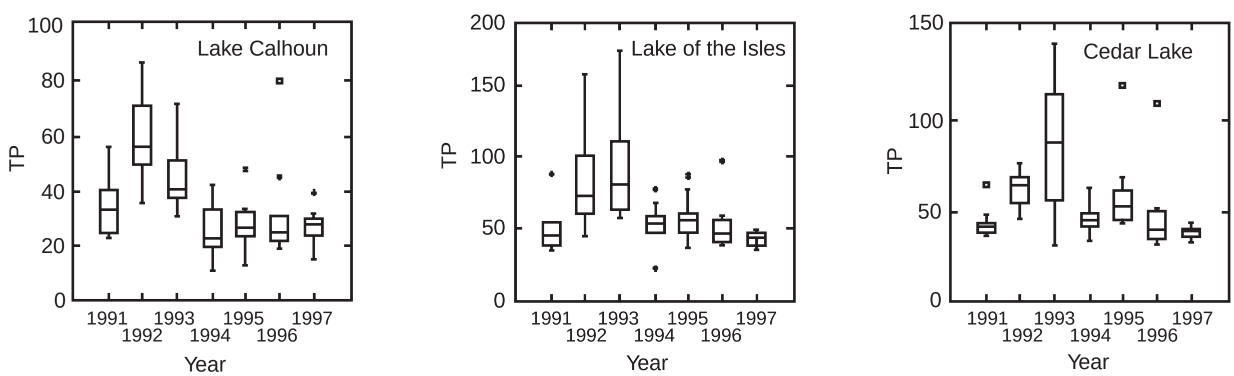

Figure 2. Growing season total phosphorus data for 1991 - 1997 for the Minneapolis Chain of Lakes (values in µg/L; mean, 25th and 75th percentile box plot).

Table 3. Post-implementation Watershed Load Projections, Predicted In-lake Total Phosphorus Concentrations, and Mean Growing Season Total Phosphorus Concentrations (1996-1997)

Lake		Cedar	Isles	Calhoun
Load Source (kg phosphorus/yr)				
Precipitation		38.5	23.4	95.5
External load		154.4	155.2	366.7
Internal load[5]		38	17.15	232.5
Other		9.2	54.4	107.3
Total (kg/yr)		240.1	250.15	802
Loading reduction (kg phosphorus/yr)		104.3	41.85	406.9
In-lake Water Quality				
Predicted	Total P (µg/L)[6]	30	42	22
Lake goals	TotalP (µg/L)	25	40	25
G.S. Mean (96-97)	Total P (µg/L)	27.5	37	27.5

(5) Internal load reduced by 50% (representing average reduction over life of treatment).
(6) Predicted values derived using Dillon and Rigler (1974).

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Restoration in the Sunshine: Retrofitting the Watersheds of Two Urban Lakes in Florida

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Because of its karst geology and generally flat terrain, Florida is dotted with numerous shallow lakes. The shallowness of the lakes, combined with generally warm temperatures and long periods of sunlight, make these lakes particularly susceptible to anthropogenically accelerated eutrophication, resulting in poor habitat and water quality. In response to citizen complaints regarding degraded water quality of two lakes in Pinellas County, the Southwest Florida Water Management District and two local governments conducted diagnostic/feasibility studies to develop restoration strategies and projects. Although the technical aspects of retrofitting the watersheds and restoring the lakes were daunting, the inter-governmental coordination, regulatory, and social hurdles were far more difficult to overcome and have caused significant delays to restoration activities. This paper will review the watershed retrofit and restoration activities for Lakes Maggiore and Seminole, and highlight several unique technical solutions proposed for the projects. The many pitfalls encountered while conducting these two projects, and strategies for avoiding them, will be discussed.

Introduction

Florida's landscape is dotted with over 7,000 generally shallow lakes. Many of these lakes are found within urban areas or areas undergoing rapid urbanization, particularly in the Central Florida corridor which includes the metropolitan areas of Tampa/St. Petersburg, Lakeland/Winter Haven, and Orlando. Because of Florida's subtropical location and climate, the growing season for algae and other aquatic plants is typically year round. Adding pollutant and nutrient-laden stormwater runoff to these shallow urban lakes creates the potential for accelerated eutrophication and accompanying problems of algal blooms, fish kills, cattail and hydrilla infestations, and the general degradation of the ecological and aesthetic qualities of these systems. Although Florida is a leader in stormwater regulation and treatment, state stormwater regulations have been in place only since 1984, and most of the urban development that is responsible for degrading these urban lakes occurred long before.

Techniques for effectively treating stormwater (e.g., wet detention) generally are well established, but depend on a minimum amount of open land. The difficulties of retrofitting stormwater systems in urban areas are thus largely a matter of having undeveloped land available upon which to construct treatment systems. Obviously, undeveloped land is infrequently available, and if it is, it is typically quite expensive. Although the technical difficulties of retrofitting urban watersheds can be daunting, the political and regulatory hurdles can be even more challenging. Overlapping municipal and agency jurisdictions and responsibilities frequently result in "turf wars" that can slow restoration projects and ultimately increase the cost of implementation. Administrative requirements within local governments and agencies to develop agreements for funding and project contracts can also significantly delay and increase overall retrofit costs.

In this paper, case studies of two urban lake restoration projects currently underway in Pinellas County, FL, will be presented. These two projects demonstrate the great opportunities, as well as the prodigious challenges encountered while attempting to retrofit highly developed urban watersheds and improve the ecological and aesthetic qualities of important urban resources.

Lake and Watershed Descriptions

Lakes Maggiore and Seminole are located in Pinellas County, FL (Figure 1). Lake Maggiore is a 386-acre lake located just south of downtown St. Petersburg, while 684-acre Lake Seminole is near the cities of Largo and Seminole in central Pinellas County (Figure 1). Land use in the watersheds of both lakes (Table 1) is largely residential, light industrial, and commercial, although there are public parks located on the shores of both lakes. Additionally, there is a large upland habitat preserve (Boyd Hill Nature Park) on the western shore of Lake Maggiore. Of the developed portions of the watersheds of both lakes, only a small fraction (approximately 11%) receives stormwater treatment based on 1984 state regulations.

Both lakes support boating, fishing, and water skiing, although the degraded conditions have curtailed these activities, particularly in Lake Maggiore. Lake Maggiore was the site of a major annual hydroplane race until a driver

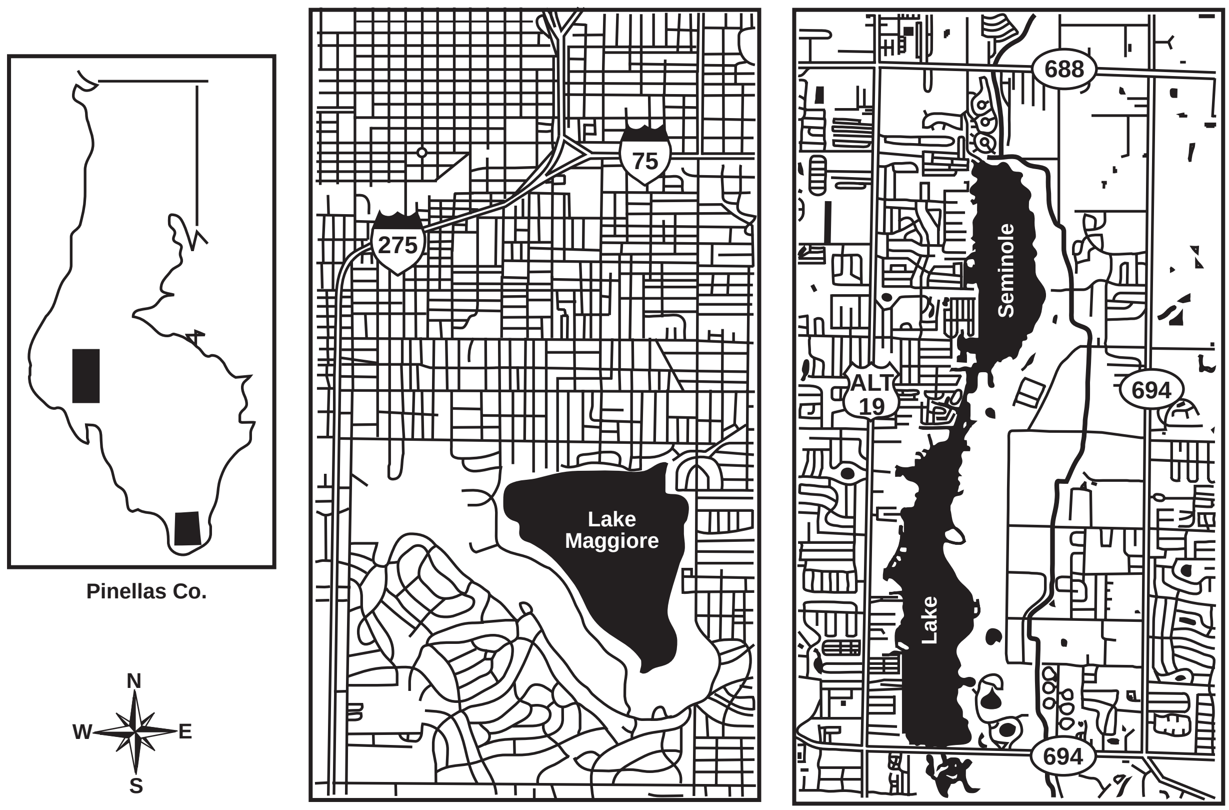

Figure 1. Lake Maggiore and Lake Seminole.

Table 1. Land Use Data for Lake Maggiore and Lake Seminole Watersheds, Pinellas County, Florida.

	Lake Maggiore[1]		Lake Seminole[2]	
	Acres	Percentage	Acres	Percentage
Commercial/Industrial/Public	94	4.1%	510	15%
Pond	64	2.8%	N/A	N/A
Undeveloped/Open/Recreational	*1448*	*63.2%*	*2554*	*73%*
Low Density	671	29.3%	1766	50%
Medium Density	690	30.1%	521	15%
High Density	87	3.8%	267	8%
Overall Total	*2291*	*100%*	*3489*	*100%*

[1] Source - Harper, H. and J. Herr, 1994.
[2] Source - Southwest Florida Water Management District and Pinellas County Department of Environmental Management, 1992.

was thrown from his boat during a crash, and subsequently developed a serious waterborne infection which resulted in hospitalization. Since then, conditions on the lake have been deemed by the City of St. Petersburg to be too dangerous for water contact sports.

Diagnostic/feasibility studies, conducted for both lakes in the early 1990's, identified the source and magnitude of nutrients and pollutants entering the lakes. Not surprisingly, both lakes have high levels of nitrogen, phosphorus, and chlorophyll (Table 2) and are highly productive. Florida Trophic State Indices (TSI) were calculated for each lake and annual averages ranged between 75 and 85 for both, indicating eutrophic to hypereutrophic conditions. Comparisons of water quality with other Florida lakes (Table 3) indicate that both lakes are among the most degraded in the state. Biological communities of both lakes were dominated by undesirable species of fish, algae, macrophytes (especially cattails), and invertebrates.

Large monocultures of cattails in both lakes have contributed to general habitat degradation and significant addi-

Table 2. Water Quality Data for Lake Maggiore and Lake Seminole, Pinnellas County, FL.

	Lake Maggiore[1] 1992-1997		Lake Seminole[2] 1991-1997	
Parameter	Median	Range	Median	Range
Total Phosphorus (mg/L)	0.059	0.005-0.394	0.10	0.02-1.01
Total Nitrogen (mg/L)	2.42	0.437-9.04	1.90	0.02-7.53
Chlorophyll *a* (µg/L)	87.8	14.8-620	62.6	5.34-144
Secchi Depth (m)	0.28	0.11-1.1	0.38	0.15-0.9
Florida Trophic State Index	82.7	55.4-104	80.8	36.4-111.4

[1] Source - Southwest Florida Water Management District, unpublished data.
[2] Source - Pinellas County Department of Environmental Management, unpublished data.

Table 3. Comparison of Water Quality Data for Lake Maggiore and Lake Seminole (Pinellas County, FL) to Water Quality Data for Florida Lakes Reported by FDEP (Friedemann and Hand, 1989). The Florida Percentile Shows the Ranking for Each Parameter among the Percentile Distribution Listed by FDEP for Median Values for their Florida Lake Database for 1970 to 1987.

Lake Maggiore[1]	Median Value 1992-1997	Percentile of FL Median Values
Total Phosphorus (mg/L)	0.059	45 (864 lakes)
Total Nitrogen (mg/L)	2.42	86 (781 lakes)
Chlorophyll *a* (µg/L)	87.8	94 (550 lakes)
Secchi Depth (m)	0.28	3 (782 lakes)
Florida Trophic State Index	82.7	97 (756 lakes)
Lake Seminole[2]	**Median Value 1992-1997**	**Percentile of FL Median Values**
Total Phosphorus (mg/L)	0.10	67 (864 lakes)
Total Nitrogen (mg/L)	1.90	80 (781 lakes)
Chlorophyll *a* (µg/L)	62.6	88 (550 lakes)
Secchi Depth (m)	0.38	5 (782 lakes)
Florida Trophic State Index	80.8	96 (756 lakes)

[1] Source - Southwest Florida Water Management District, unpublished data.
[2] Source - Pinellas County Department of Environmental Management, unpublished data.

tion of organic materials to the sediments. Additionally, the profusion of tall stands of cattails have generated numerous citizen complaints regarding obstructed views of the lakes (particularly Lake Maggiore) and the role cattails play as havens for mosquitoes, rodents, and undesirable reptiles (alligators and snakes).

Recommendations from both diagnostic studies centered on treating stormwater runoff, coupled with specific in-lake restoration projects, to substantially improve water quality in the two lakes. For Lake Maggiore, this required whole lake dredging and retrofitting the watershed to appreciably reduce nutrient sources to the lake. For Lake Seminole, it is expected that some dredging, along with retrofitting, will be required.

Restoration Approach - Lake Maggiore

To initiate the Lake Maggiore restoration project, the city approached the district to fund a diagnostic/feasibility study. The district agreed to fund a $160,000 study with in-kind contributions from the city. The city's Engineering Department was designated to manage the entire lake restoration project. Their first task was to establish an advisory committee charged with providing input to, and overseeing the progress of, the diagnostic study. The committee, which included local citizens, representatives from environmental organizations, and government agencies reviewed the results of the diagnostic study and selected a TSI of 60 as the target water quality goal for the lake.

To achieve the target TSI for Lake Maggiore, it was determined that retrofitting as much of the watershed as possible was required. This was obviously a technically challenging and expensive proposal because of the lack of available undeveloped land for construction of standard wet detention systems. Although there is substantial undeveloped city-owned land surrounding the lake, including a public park and the Boyd Hill Nature Preserve, a strict city ordinance prohibits stormwater treatment facilities on these lands. Thus, a creative and less land-intensive solution was required, and the ultimate treatment option chosen was alum injection.

Alum (aluminum sulfate) has long been used in drinking water treatment and wastewater treatment to remove particulate matter and phosphorus (P). In Florida, the use of alum to remove P from stormwater runoff entering lakes has been effective as a restoration tool for numerous urban lakes, particularly in the Orlando area. Treatment typically consists of injecting a calibrated dose of alum solution into a stormwater stream to precipitate the dissolved and particulate P and thereby reduce the in-lake P concentration; and ultimately reduce algal populations within the lake. Alum injection systems are compact, and this was viewed as a desirable feature for installation at Lake Maggiore. All the pumps, control panels, piping, and alum storage tank could be placed in a very small area, approximately the size of a one- or two-car garage. Additionally, a number of stormwater outfalls to the lake could be treated from a single system through a manifold. Finally, the cost of constructing alum injection systems was considerably less than condemning and purchasing property for construction of standard wet detention systems.

Five alum injection sites were constructed to treat over 63% of the runoff from the watershed and reduce the amount of P entering the lake by 80%. Construction was completed in the fall of 1997, and the injection devices should be in operation by February of 1998. Stormwater from the remaining untreated portion of the watershed (eastern side of the lake) will be directed through a wet detention system to be constructed as part of the proposed dredging project.

Whole lake dredging was proposed as another major restoration project for Lake Maggiore. The lake bottom is covered with over 2.3 million cubic yards of organic deposits and fine sediments which are a source of nutrients and create significant oxygen demand during the warmer months. Thus, to reach the TSI goal set for the lake it would be necessary to remove the bulk of these sediments in addition to treating the stormwater. The land requirements needed for this project were particularly difficult to meet since it was not possible to use the city-owned land around the lake for processing or disposal of the dredge spoil. The cost of transporting the spoil to a landfill or other offsite property was prohibitive, so a unique solution was proposed to dewater the sediments in an effort to reduce spoil disposal costs.

The proposed solution for dewatering the sediments, developed for the phosphate industry to settle out clay particles, involved introducing organic polymers into the dredge spoil, followed by screening the material to separate out the aqueous fraction. Untreated dredged material from Lake Maggiore is expected to have a solids content of 4-6%, while the polymerized material is expected to have a solids content of 10-15% immediately after treatment and 30-40% after rapid drying. This treated spoil material could be easily transported within seven days of dredging (weather permitting).

Despite reducing the amount of spoil to be transported, it still would not be possible to cost- effectively transport all the sediments to a landfill. Therefore, an option was investigated that involved pumping a portion of the dredge spoil to several old borrow pits located within the city. Because of opposition from the public and the State Departments of Transportation and Environmental Protection, this option was abandoned. Subsequently, another option was developed that proposed that a portion of the lake could be filled with the dewatered spoil to create a public park, and a wet detention system could be built to treat the stormwater runoff from the eastern watershed. Although the proposal included filling in 34 acres of the 386 acre lake to accomplish this task, it was believed that the water quality and habitat benefits were worth transforming that amount of lake bottom. However, regulatory and permitting agencies did not completely agree with our cost/benefit analyses and at this time the permit is still being reviewed by the US Army Corps of Engineers. When, and if, the project is approved, it should take 18 months to two years to complete.

Several smaller projects were proposed and have been implemented for Lake Maggiore, including the construction of a new operable outfall structure from the lake to allow future drawdowns and sediment consolidation, the removal of large cattail stands on the eastern shoreline and revegetation of the site with desirable aquatic plants, and the purchase of an aquatic plant harvester to remove cattails and other undesirable aquatic plants on an ongoing basis.

Restoration Approach - Lake Seminole

As with Lake Maggiore, a local government, Pinellas County, sought funding from the District for a diagnostic/feasibility study of Lake Seminole. The District expended over $400,000 on a detailed study to document the sources and magnitude of nutrients and pollutants entering the lake. Pinellas County put its Department of Environmental Management (DEM) in charge of the project. Like the city, DEM formed an advisory committee comprising similar interest groups and agencies. Once the study was completed, the committee recommended a water quality target TSI of 60, the same as for Lake Maggiore.

One of the conclusions of the diagnostic study, that the eutrophic condition of the lake was the result of untreated stormwater runoff entering the lake, was similar to that of the Lake Maggiore study. In contrast to Lake Maggiore, the Lake Seminole study identified only small pockets of organic sediment within the lake basin and, thus, no large dredging project was proposed. Retrofitting the Lake Seminole watershed posed the same difficulties encountered at Lake Maggiore, since there was only a small parcel of open land potentially available for standard wet detention treatment systems. The parcel, which the county purchased for $1.9 million, comprised five usable upland acres on the shore of the lake and was the last open land available around the lake.

The county has not yet settled on one type of retrofit system for the watershed. Rather, a consultant is preparing a watershed management plan that is expected to propose a mix of retrofit solutions. The original diagnostic study identified several sub-basins within the watershed that contribute significant amounts of nutrients to the lake, and within which several remedial actions could be implemented immediately. On the five-acre parcel, a wet detention system was proposed that would incorporate a state-of-the-art system employing a residence time of nearly 14 days. At another site, an existing retention pond was redesigned to improve its treatment capabilities by reducing the slope, meandering the banks of the pond, and planting native wetland vegetation. An operable structure has been installed at the pond outfall to allow for drawdowns and cattail removal. Finally, untreated runoff from a 15-acre residential area will be routed through a refurbished wetland on the property of a local junior college. Like the five acre parcel, this system will provide a 14-day residence time prior to discharge. Once the watershed management plan is complete, additional retrofit projects will be proposed and implemented.

A unique retrofit project currently being considered for the restoration of Lake Seminole incorporates two state-of the-art technologies. This project proposes to link a vortex trash and sediment collector (CDS Technology) with an alum injection system. The vortex system would remove large sediment particles and trash while the alum injection system would inactivate the soluble phosphorus in the runoff. Both systems require only small amounts of land for installation and may fit into existing stormwater collection systems. Such integrated systems may be especially well suited to the Lake Seminole watershed, since many of the streets on the western (heavily developed portion) shore of the lake collect stormwater and discharge directly to the lake through pipes at the end of each street. A total of 75 such discharges have been identified along the western shoreline of Lake Seminole.

Like Lake Maggiore, Lake Seminole has expansive growths of cattails that have degraded the littoral habitat and caused citizen complaints about obstructed lake views. The county experimented with several cattail removal/ revegetation projects and, as with the city, was provided with an aquatic plant harvester purchased by the district. These projects met with some difficulty. Particularly the revegetation portion, where grass carp, introduced earlier to eradicate hydrilla, ate the newly planted vegetation. Ultimately plastic fences were constructed to bar the carp from these sites until the new vegetation became properly established; however, cattail removal has proven to be an expensive and problem-plagued undertaking.

Lake Seminole discharges over a fixed crest weir to Boca Ciega Bay during high water periods. A recommendation from the diagnostic study was to replace the weir with an operable structure so the lake could be periodically drawn down for sediment consolidation purposes and cattail removal. This structure is currently in the design stage and is expected to allow a maximum three feet fluctuation in lake levels.

Success is a Four Letter Word

Although funding such large scale lake restoration projects is often a difficult undertaking, all three entities involved in both projects (the district, the City of St. Petersburg, and Pinellas County) initially were enthusiastic about providing adequate funding. The district provided $5 million for each lake while the city and county were responsible for an additional $5 million each for their specific project. Ten million dollars for each project seems generous, but as the recommendations of the diagnostic studies reached the design stage it was obvious that timely implementation of the retrofit and in-lake restoration projects was going to be difficult to fully achieve. And it is well known that “time is money.”

For the restoration of Lake Maggiore, the city had to win the confidence of a very active environmental group associated with the Boyd Hill Nature Preserve. Previous adversarial interactions with city government had caused this group to be suspicious of any “environmental improvement” project sponsored by the city. Although the city had disbanded the advisory committee, a number of meetings were held with this group and homeowner committees to allay concerns and, ultimately, these groups endorsed the overall project; however, they vehemently opposed any use of public lands (park land) for either retrofit or dredging. This opposition had serious financial implications for both aspects of the restoration in that (1) land would not be available to construct small ponds at the alum injection sites for collecting the precipitate prior to disposal at a landfill and (2) there would be no land available around the lake or any other nearby public land on which to place the dredge spoil. Both these difficulties required time and project redesign to solve.

The alum pond problem was resolved when the city Engineering Department approached the owners of a nearby private golf club and sought their approval to use the course’s water features as alum collection ponds. In exchange for improvements to several drainage features on the golf course, club officials agreed to the city’s request, and the alum injection project was able to move forward.

In contrast, the dredging was (and still is) far more challenging. In addition to the lack of available land, the dredging project ran into serious regulatory difficulties. Although it would seem the environmental benefits and public interest being served would help propel the project quickly through the permitting process, it became obvious that this was wishful thinking. In fact, because this project was not a private venture but was government sponsored, it seemed as though the restoration team was compelled to jump additional regulatory hurdles to ensure compliance with every last letter of the law. Dredging the lake presented a number of regulatory issues that were capable of being resolved relatively quickly with the state agency responsible for issuing the permit; however, because there was no spoil disposal site within the watershed, the project was redesigned to place the spoil on 34 acres of lake bottom adjacent to the eastern shore. This aspect of the project was and continues to be a permitting challenge, since placing spoil on sovereign submerged land in Florida is severely restricted and requires the approval of the Governor and Cabinet. Additionally, Lake Maggiore and all of the natural waterbodies of the county are considered Outstanding Florida Waters. This special protective state designation limits any developmental activities within the waterbody, especially dredging and filling.

To make this design acceptable to the permitting agencies, additional stormwater treatment was incorporated within the 34-acre spoil site, and the city designed a park with extensive boardwalks and environmental exhibits. However, the features designed into the site were of less concern to the regulatory authorities than the fill itself. Ultimately the site was redesigned to allow only eight upland acres for the park with the remaining 26 acres used for constructed wetlands and littoral zones. The state permit was obtained after over one and a half years of frustrating, contentious meetings and failed compromises, including three trips to the state capital to win approval of the Governor and Cabinet. Soon after the state permit was received and bids were being prepared for a dredging contractor, the Corps of Engineers (COE) asserted their displeasure with the design, which has further delayed permitting (in fact, the COE has still not issued a permit or ruling). The economic feasibility of conducting this project is now in question, since the various delays and project redesigns (including transporting the bulk of the spoil ten miles for disposal) have escalated the costs beyond the initial project budget.

For Lake Seminole, the regulatory issues to date have not been as onerous; however, the administrative difficulties of implementing projects have been as frustrating as the permitting problems for Lake Maggiore. Approval of funding agreements and project contracts between Pinellas County and the district was often a difficult and time-consuming ("time is money," again) effort because of the many steps involved in the approval processes for both entities. In one egregious case, a full year was spent ("time is money") developing a contract with language acceptable to lawyers and contract managers for the county and District. This issue was finally resolved when the District's project manager requested a meeting of all lawyers and contracts personnel from both entities. This illustrates the need to account for the slow pace of administrative processes in any restoration time-line.

Although the diagnostic study for Lake Seminole and recommendations for restoration activities were completed in 1992, project implementation has been slow. In addition to the contract approval process, the county has taken a very cautious approach to selecting projects for retrofitting the watershed and restoring the lake. This is the result of a proposed retrofit plan for another watershed in the county that generated extremely negative outcries from the citizens involved. Since then, county staff have developed a very deliberate process for evaluating projects for the Seminole watershed and have provided numerous opportunities for public input. Although several retrofit projects were selected for immediate design as a result of the 1992 diagnostic study, the county insisted on having a watershed management plan developed before proceeding with additional retrofit projects. In the preparation of this plan, the consultant is duplicating some of the work conducted in the original diagnostic study, and this plan will not be available until the summer of 1998.

Changes in project managers at both the district and county and changes in project implementation responsibilities at the county have resulted in miscommunication and project coordination problems that have delayed the overall restoration effort for Lake Seminole. In 1996, the county shifted responsibility for conducting the project from the DEM to the Engineering Department and simultaneously changed project managers. At about the same time, the district also changed project managers. Overall, these changes have been very positive, but have led to delays in several projects while the personnel involved became familiar with the projects and each other.

Unlike the city, the county had maintained an advisory committee of some kind since the inception of the restoration project in 1991. This committee originally consisted of staff from various government agencies, as well as concerned citizens. Initially, there was a great deal of enthusiasm from citizen members who had felt that once the diagnostic study was complete implementation of restoration projects would begin and their lake would soon be restored. Their enthusiasm was manifested in the establishment of a lake protection group that sponsored lake cleanup days, stormdrain painting efforts, and lobbying of the agencies involved to expedite restoration projects. Once the actual project timelines became clear, they became frustrated with the slow pace of implementation, their enthusiasm rapidly waned, and their attendance at the committee meetings ended. Now, the committee is composed almost entirely of agency staff and consultants and is singularly lacking in citizen participation. As with Lake Maggiore this lack of citizen involvement may hinder the implementation of future projects.

Lessons Learned (The Hard Way!)

The first step of any lake restoration project is the completion of a thorough diagnostic/feasibility study to determine the source and magnitude of pollutants influencing water quality and to develop remedial strategies. This may seem obvious, but many citizens and municipal officials see this work as a waste of money since they claim to know the cause of problems in their lake. The expenditure of millions of dollars on projects designed on anecdotal evidence would be negligent on the part of any responsible lake manager and should be vigorously resisted.

Once retrofit or in-lake restoration projects and their costs have been identified, all possible funding options should be sought. If the financing of a particular project can be split between several entities, the project is often easier to sell to those responsible for approving the funds since leveraging limited funding, especially in the form of a "public/private" partnership, is attractive to most local governments. Again, this strategy would seem obvious, but other state, private, and federal funding sources are often overlooked.

Solid intergovernmental cooperation and coordination are essential to the timely and effective implementation of any restoration project; however, these elements of effective communication are often lost in the "turf" battles that can occur between and inside large agencies. If permits are needed to implement a retrofit or in-lake project, ensure that all appropriate agencies and authorities (local, regional, state, and federal) are included and participate from the beginning. Costly delays to the Maggiore and Seminole projects have resulted not only from classic bureaucratic inertia, but also from not providing sufficient information to the permitting agencies responsible for approving the projects. More frequent meetings with all the regulatory personnel involved may have helped identify permitting problems, and thus lessened the time spent seeking permits and developing alternative solutions for unpermittable activities. However, the narrow interpretation by the regulating agencies of the rules governing the projects and the negligible credit received for the "net environmental benefit" of the overall restoration remains a source of extreme frustration for the project managers and citizens who will benefit from the projects.

For both Lakes Maggiore and Seminole, the most significant lesson learned was the need to thoroughly educate the public, the regulatory/permitting staff, and the politicians as to the goals, objectives, and time-lines of the overall projects. Garnering public support for lake restoration is absolutely crucial in all aspects of the project, from funding to implementation. Maintaining the public's interest in a typically lengthy restoration process requires that small, quickly implementable projects be proposed and completed to demonstrate some immediate benefit to the citizens. And, as noted earlier, adequately educating politicians and regulators will be the only way these projects can be appropriately funded and permitted in a timely manner.

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Retrofit Study for the Lower Neshaminy Creek Watershed

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The Lower Neshaminy Creek watershed is a densely developed area in the Bucks County, Pennsylvania, coastal zone. Historically, stormwater best management practices (BMPs) consisted of stormwater management basins designed only to control flooding. Water quality was a secondary concern. Retrofit options to meet the water quality control requirements of section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) have been developed. Fifteen basins having different design features and draining different land uses were selected as examples. Retrofit recommendations focus on low-cost design and maintenance options that landowners or local governments can implement. Graphics were developed that demonstrate the problems and illustrate the retrofit plans for each basin. The Bucks County Planning Commission plans to fund the modifications to one basin as a demonstration project.

The hydrologic and water quality benefits associated with a range of additional BMPs that are appropriate to Bucks County were also evaluated. A matrix summarizing the water quality benefits of these BMPs was developed. Implementation costs and maintenance requirements were analyzed. An easily understandable “how-to” document targeted at local government officials and staff, developers, and people who maintain stormwater management facilities was developed to present the information on retrofit options and costs, maintenance requirements, and BMP selection.

Introduction

In July 1995 the Bucks County Planning Commission (BCPC) entered into a grant agreement with the Pennsylvania Department of Environmental Protection (DEP) and the National Oceanic and Atmospheric Administration (NOAA) to complete a study involving modifying options for existing stormwater management basins in the Lower Neshaminy Creek watershed. The study focused on stormwater basins and their effect on stream water quality. By identifying problems and possible solutions for these basins, the BCPC hoped to develop guidance that could be used by local municipalities to repair malfunctioning basins or to learn to design better ones in the future. Guidance was also developed on the selection of appropriate BMPs for different development situations and the cost/benefit of selected BMPs.

Study Area

The predominant land cover in the Lower Neshaminy study area is single-family residential housing (2 to 4 dwelling units per acre). Other significant amounts of land cover in the area include multifamily residential buildings (>4 units per acre) and commercial and manufacturing structures. Minor land cover in the area includes transportation, utilities, community service, military, recreation, agriculture, mining, and vacant land. Projected future land uses include predominantly high-density residential, as well as commercial, industrial, and resource protection.

Retrofit Options for Existing Stormwater Basins

Some residential and commercial developments in the Lower Neshaminy Creek watershed have been built with one or several runoff controls on site. Most of these facilities were designed to control flooding and other hydrologic impacts from development, with little consideration for water quality control. These basins could be redesigned and retrofitted to address both the water quality and water quantity concerns in the watershed.

Stormwater Management Basins Used in the Study

Seventeen stormwater management basins in the Lower Neshaminy Creek watershed were assessed for potential retrofitting/redesign options (Figure 1). The survey of basin conditions was conducted during several site visits to the watershed during February through July of 1995. The immediate surrounding areas were also observed for problems that might have been caused by the basins, such as flooding or eroded conditions. General information regarding the physical appearance and condition of the basins, and problems including erosion, improper maintenance, and malfunctioning basin components, were noted.

Basin Summaries

After the site visits and review of the available site plans, summaries were compiled to provide a general description of the conditions at each basin. Table 1, gives examples of basin descriptive information, and the problems and suggestions for remediation. Figure 2 presents the conditions at an example basin and the types of retrofit options developed. Table 2 is a summary of the problems observed in the basins and potential solutions.

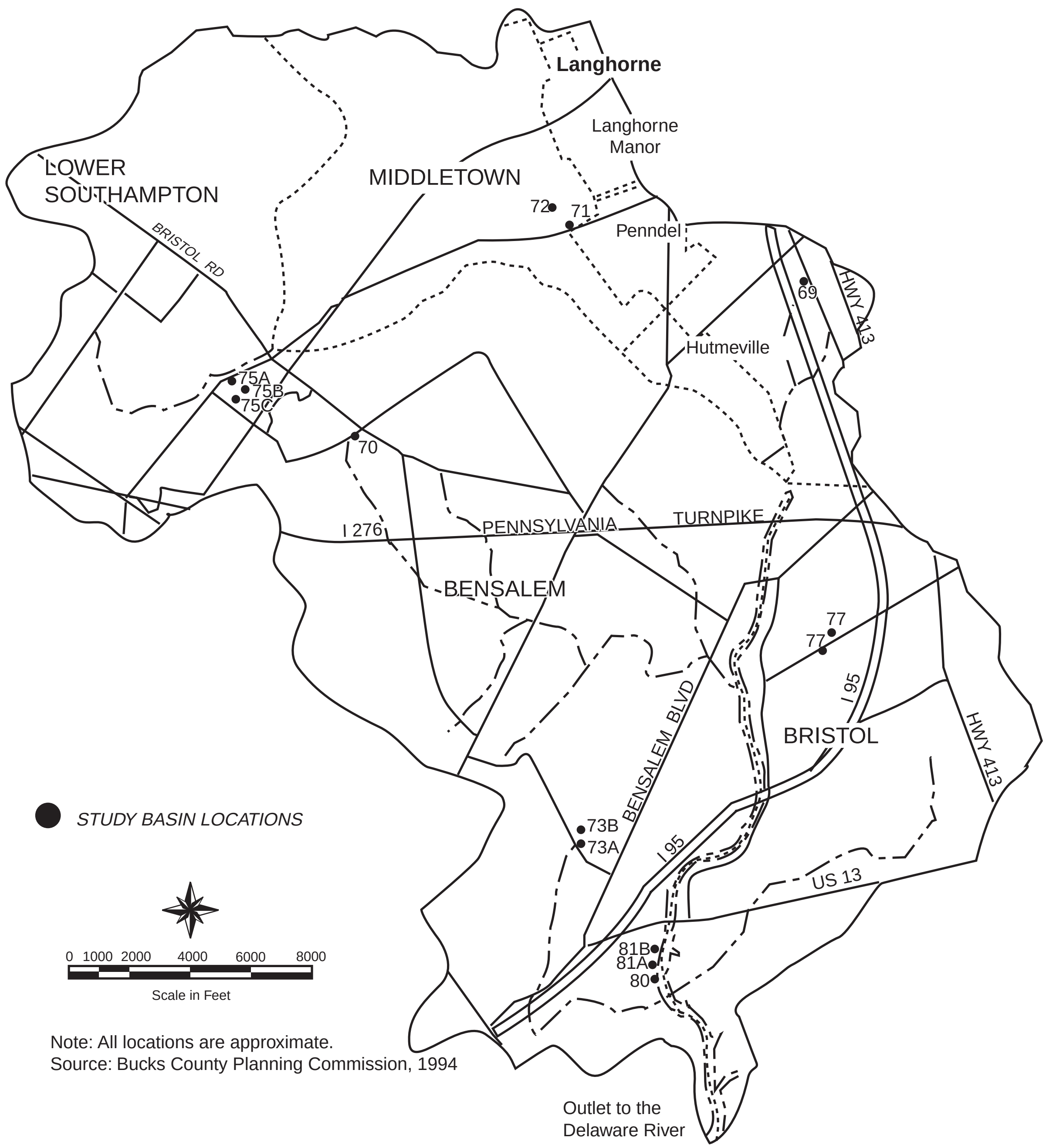

Figure 1. Map of study area, Lower Neshaminy Creek, stormwater management and water quality study.

Table 1. Example Basin Summaries

Basin	Description	Problems	Suggestions
Basin 70 - Neshaminy Square Shopping Center	• Three-stage outlet structure • Basin appears to pick up runoff from all of parking lot and entrance road as well as rooftops (downspouts discharge to surface)	• Significant erosion at far inlet manhole and catch basin at parking lot • Not well maintained: a lot of trash and discard items • Fairly steep side slopes with dead brush at several locations, very marshy on bottom • No water quality component • Algae present in both the basin and the discharge channel	• Perform maintenance (e.g., fix erosion, clean debris) • Add orifice plate* • Excavate the basin and make it into a pond • Add forebays at each inlet • Add an upstream basin • Regrade side slopes where possible and add vegetation • Install oil and grit separators at existing manholes • Install water quality or sand filter inlets*
Basin 72 - Highland Avenue	• Perforated riser; designed for water quality attenuation • Outlets to street system • Development very new • Concrete overflow spillway	• Poorly maintained basin with poor growth of grass • Needs to be regraded since invert of outlet is higher than portions of basin (causing ponding to occur) • Very steep slopes (slopes should be less for water quality purposes.)	• Regrade and reseed the slope • Plant additional vegetation • Modify slopes; perhaps add terracing
Basin 76 - Old Lincoln Highway	• Cigar-shaped (long and narrow) with steep longitudinal slope • Good stand of grass • Approximately 8-inch diameter outlet pipe • Purpose unknown; majority of parking lot bypasses basin and there is no evidence of roof downspouts	• Erosion around riprap at inlet • No water quality component	• Add orifice plate* • Add forebay at inlet • Intercept parking lot that bypasses the basin • Add vegetation • Add water quality inlets* • Add series of riprap or timber checkdams
Basin 77 - Bensalem Township Industrial Park I	• Large outlet pipe • Outlet to enclosed system; riprap overflow spillway	• Minor amount of marshy bottom • Inlet and outlet adjacent to each other (short-circuit) • No water quality component	• Add orifice plate* • Regrade or add forebays to minimize short-circuiting • Add vegetation • Add water quality inlets*
Basin 78 - Bensalem Industrial Park II	• Steep side slopes • Unconventional shape - long and linear with bulb at top • Two-stage outlet • Parking areas and rooftops drain to the basin	• Partially clogged inlets with some ponding (both typical) • No water quality component • Many tall weeds at bottom, which inhibit drainage • Some erosion on side slopes	• Perform routine maintenance • Add forebays to minimize short circuiting at inlet 2 • Regrade where possible • Add water quality inlets and/or orifice plate*

*Flood protection from large storms may be lessened when orifice plates and/or water quality inlets and outlets are installed.

It is important to note that the observations and the recommended renovations to these facilities or sites were offered for voluntary adoption by municipalities and facility owners. The retrofit procedures described in the report were not intended to be mandatory. The municipal officials and facility owners were strongly encouraged to implement any and all of the measures identified for the upgrades through mutual agreement or cooperative effort. The result of this implementation might be to reduce some types of basin failures (e.g., outlet failure, side slope failure, scouring, standing water in dry facilities), increase overall water quality associated with stormwater runoff in urban areas, and reduce the need for long-term rehabilitation or repair of these facilities.

Costs and Benefits Associated with Urban Runoff Controls

Costs of nonpoint source controls vary from site to site and area to area. Because of the variety of options available for controlling urban runoff, it is difficult to pinpoint exact costs for runoff control. An important factor that needs to be considered in determining such costs is the cost of maintaining facilities. Volume 2 of the *Neshaminy Creek Nonpoint Pollution and Wetlands Study* (Bucks County Planning Commission, 1994) presents information on the relative cost and benefit of various nonpoint source control practices. EPA's *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1993) also presents detailed information on rela-

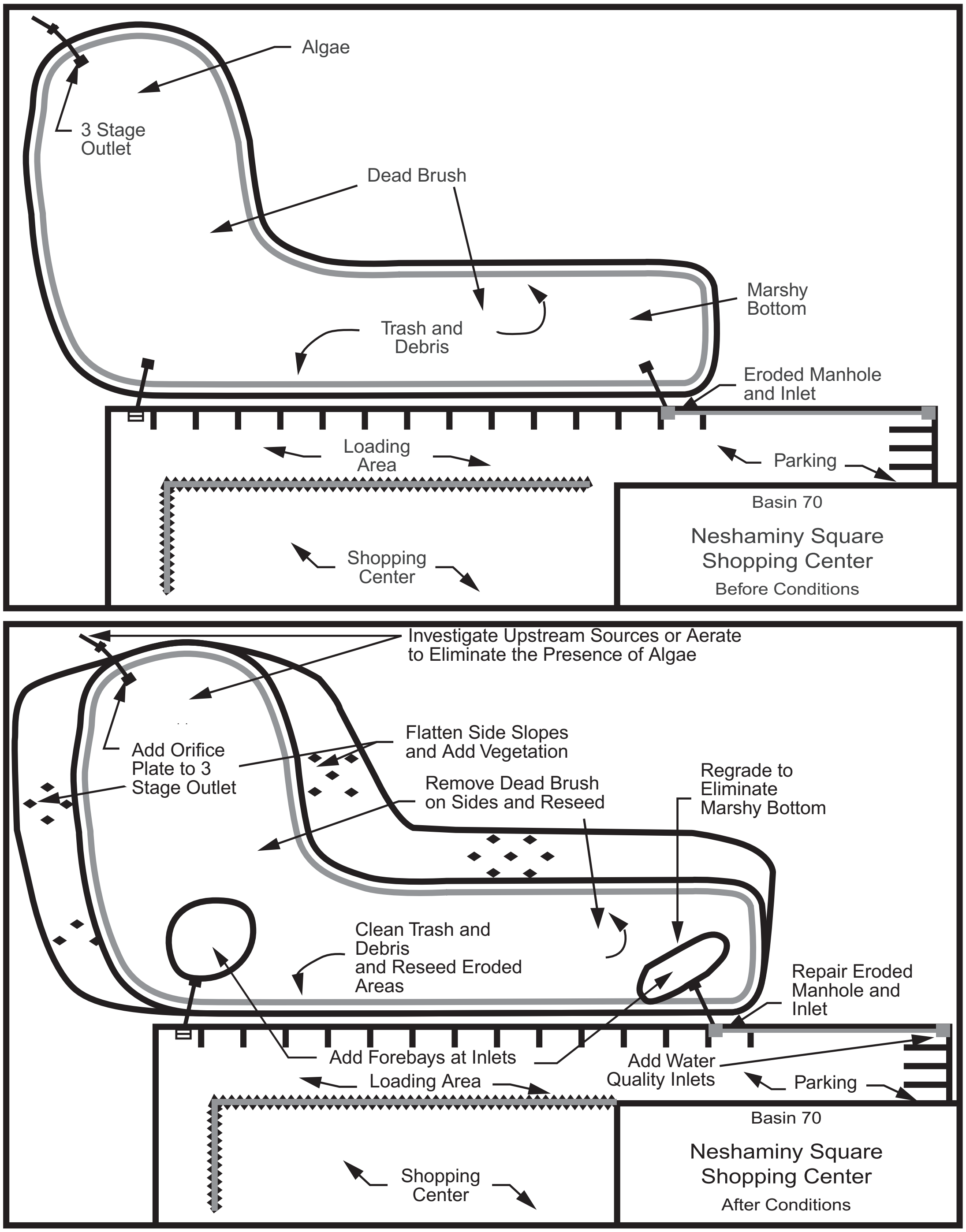

Figure 2. Before and after retrofit conditions at an example basin.

Table 2. Summary of General Problems and Solutions

Problem	Possible Solution(s)
Slide slope erosion	• Regrade slopes • Add vegetation • Install energy dissipators and/or level spreaders
Erosion around outlet structure	• Install energy dissipators/level spreaders
Receiving stream erosion	• Install riprap or similar stabilizing structure
Lack of water quality components*	• Orifice plates • Perforated riser • Sediment forebay • Water quality inlets • Vegetation • Pollution prevention
Trash	• Periodic maintenance • Trash screens
Ponding	• Regrade basins • Reset outlets where appropriate • Plant wetlands species
Sedimentation	• Sediment forebays

*Flood protection from large storms may be lessened when water quality controls are installed.

tive costs for urban runoff controls. Volume II of the *Neshaminy Creek Watershed Stormwater Management Plan* includes information on the maintenance costs associated with various stormwater management practices.

General Costs and Benefits Associated with Urban BMPs

The cost of design and installation is just a portion of the overall cost of implementing structural BMPs. The additional costs that need to be considered include routine maintenance, inspections, modifications if the system is not working properly, and retrofitting, if necessary. It is difficult to anticipate and quantify the exact costs associated with controlling urban runoff.

Cost should not be the only factor in choosing a BMP or series of BMPs. The types of pollutants removed, the feasibility of the BMP in light of site constraints, the amount of maintenance needed, and aesthetics and safety are also considerations. Table 3 provides a general overview of the benefits and disadvantages of typical BMPs, pollutant removal rates, and general construction and annual costs associated with the BMPs. Table 4 summarizes the feasibility and comparative costs for each of the BMPs. These tables are meant as guides only; actual costs may vary.

General Findings

Field assessments were performed on 17 example stormwater management basins in Bucks County, Pennsylvania. Recommendations for modifications or upgrades were applied to the example basins in many forms, including outlet modifications, grading, inlet modificafions, vegetation changes, fencing, and general maintenance procedures. Each basin was documented in “before” and “after” conditions, and changes were discussed in detail. Costs were considered in an attempt to evaluate how “achievable” these modifications could be, assuming that the lower the relative cost, the more likely that the modification could be done. Due to the desire to include a water quality component, the structural modifications were evaluated from the standpoint of how to improve water quality functions. Modifications ranging from costly ($89,700) to reasonable ($10,000) were developed for each individual basin. Information was also presented on the relative costs and feasibility of installing a variety of other BMPs.

Table 3. BMP Benefits and Costs

BMP	Beneficial for:	Beneficial with some Limitations for:	Advantages	Disadvantages	Pollutants Removed (Average % Efficiency)	General Cost
Extended Detention - Dry Pond	• Flood control • Erosion control	• Water quality	• Provides peak flow control • Provides good particulate removal • Can serve larger develop-ments • Usually does not release warm or anoxic water downstream • Provides excellent protection from down-stream erosion • Can create wetland and meadow habitat when landscaped properly	• Removal rates for soluble pollutants are low • Not economical for drainage areas less than 10 acres • If not adequately main-tained, can become an eyesore and health hazard • Improper design can lead to significant reduction in efficiency • Extremely large storms tend to "blow through" the system, reducing pollutant removal	• TSS (45%) • Phosphorus (25%) • Nitrogen (30%) • COD (20%) • Lead (50%) • Zinc (20%)	<u>Construction</u> $0.50/ft^3$ <u>Annual</u> $0.30/ft^3$
Wet Pond	• Flood Control • Erosion control	• Water	• Provides peak flow control • Cost-effective for larger, more intensely developed sites • Enhances aesthetics and can provide recreational benefits • Helps to prevent scour and resuspensions of sediments • Provides good nutrient removal	• May not be economical for drainage areas less than 10 acres • If not properly main-tained can become an eyesore and safety and health hazard • Requires considerable space • Not suitable for hydro-logic soil groups A and B in the NRCS classifi-cation unless the pond is lined, or inappropriate soils are replaced with more appropriate soils • Possibility of release of warm and anoxic water which may impact downstream aquatic life	• TSS (60%) • Phosphorus (45%) • Nitrogen (35%) • COD (40%) • Lead (75%) • Zinc (60%)	<u>Construction</u> (pond < 1 million ft^3) $0.50/ft^3$ (pond > 1 million ft^3 $0.25/ft^3$ <u>Annual</u> $0.008 - 0.07/ft^3$ quality
Vegetated Filter Strip	• Water quality • Erosion control	• Flood	• Low maintenance requirements • Can be used as part of the runoff conveyance system to provide runoff pretreatment • Can reduce particulate pollutant levels in areas where runoff velocity is low to moderate • Provide urban wildlife habitat • Economical	• Can concenterate water, which signi-ficantly reduces effectiveness • Ability to remove soluble pollutants is highly variable • Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated • Requires periodic repair, regrading, and sediment removal to prevent channelization	• TSS (65%) • Phosphorus (40%) • Nitrogen (40%) • COD (40%) • Lead (45%) • Zinc (60%)	<u>Construction</u> (*existing vegetation*) $0/acre (*seeding*) $400/acre (*seed and mulch*) $150/acre (*sod*) $11,300/acre <u>Annual</u> - Natural succession (*existing vegetation*) $100/acre (*seed*) $125/acre (*seed and mulch*) $200/acre (*sod*) $700/acre

(continued)

Table 3. Continued

BMP	Beneficial for:	Beneficial with some Limitations for:	Advantages	Disadvantages	Pollutants Removed (Average % Efficiency)	General Cost
						<u>Annual</u> - No natural succession (*existing vegegation*) $800/acre (*seed*) $825/acre (*seed and mulch*) $900/acre (*sod*) $1400/acre control
Grassed Swale	• Erosion control	• Water quality • Flood control	• Requires minimal land area • Can be used as part of the runoff conveyance system to provide pretreatment • Can provide sufficient runoff control to replace curb and gutter in large-lot single-family residential developments and on highway medians • Economical	• Low pollutant removal rates • Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	• TSS (60%) • Phosphorus (20%) • Nitrogen (10%) • COD (25%) • Lead (70%) • Zinc (60%)	<u>Construction</u> (*seed*) $6.50/lin ft (*sod*) $20/lin ft <u>Annual</u> (*seed*) $1/lin ft (*sod*) $2/lin ft
Constructed Wetlands	• Flood control • Erosion control	• Water quality	• Can serve large developments; most cost-effective for larger, more intensely developed sites • Provide peak flow control • Enhance aesthetics and provides recreational benefits • Prevents shoreline erosion • Helps prevent scour and resuspension of solids • High pollutant removal potential	• Not economical for drainage areas less than 10 acres • Potential eyesore and health and safety hazard if not properly maintained • Requires large land area • Possible thermal and anoxic discharge, which could impact downstream aquatic life • May contribute to nutrient loadins during vegetation die-down periods	• TSS (65%) • Phosphorus (25%) • Nitrogen (20%) • COD (50%) • Lead (65%) • Zinc (35%)	<u>Construction</u> $50,000-$100,000/acre (This is based on actual construction costs for a development in northern Delaware)
Sand Filter	• Water quality • Erosion control	• Flood control	• Provides high removal efficiencies of particulates • Requires minimal land area • Provides flexibility to retrofit existing small drainage areas • High removal of nutrients	• Not feasible for drainage areas greater than 5 acres • Feasible only in areas that are stabilized and highly impervious • Not effective as water quality control for intense storms	• TSS (80%) • Phosphorus (60%A) • Nitrogen (35%) • COD (55%) • Lead (80%) • Zinc (65%) • Oil and grease (75%)	<u>Construction</u> $\$5/\text{ft}^3$ <u>Annual</u> $\$0.10 - 0.80/\text{ft}^3$

Sources include: MWCOG, 1992; Terrene Institute, 1994; USEPA, 1993, 1996.

Table 4. Relative Costs and Feasibility

BMP	Relative Cost	Feasibility Factors
Extended Detention - Dry Pond	Lowest cost alternative in its size range	• Good if used in conjunction with pretreatment (e.g., sediment forebay, grassed swale) • Requires dedication of land that could otherwise be used for buiding • Viable option if downstream flooding is a concern
Wet Pond	Moderate to high compared to alternatives; however, maintenance requirements tend to be less than with dry ponds	• Provides aesthetic benefits (which could be translated into economic benefits for developers) if creatively designed and properly maintained • Requires dedication of land that could otherwise be used for building • Viable option if downstream flooding is a concern
Vegetated Filter Strip	Low comparative cost	• For use in areas where land can be dedicated for stormwater runoff control • Better for new development than for retrofit in already developed areas • Can be incorporated into the landscape of a development, adding aesthetic value
Grassed Swale	Low compared to curb and gutter	• Requires some maintenance (mowing, cleaning trash) • More aesthetically pleasing than curb and gutter
Constructed Wetlands	Marginally higher than wet ponds	• Provides habitat • Can be used as a selling point for developments • Requires some maintenance (more until wetlands become established) • Should be used in conjunction with other BMPs (e.g., sediment forebay, swales, etc.) to maximize wetland potential
Sand Filters	Comparatively high construction costs; requires regular maintenance	• Disposal of "dirty" sand may be a waste disposal issue in industrial areas because of contents of sand (hydrocarbons, heavy metals, etc.) • Good for use in areas where land is not available for ponds (e.g., retrofit areas) • High TSS removal rate is a definite benefit

Sources include: MWCOG, 1992; Terrene Institute, 1994; US EPA, 1993, 1996.

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The Stormwater Management StormFilter™

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Introduction

Since 1991, the StormFilter™ (formerly the CSF® Stormwater Treatment System) has been treating stormwater runoff from small single retail sites to large urban parking lots, residential streets, urban roadways and freeways. The StormFilter™ is a filtration Best Management Practice (BMP) used for removal of pollutants from stormwater. The flow-through system is housed in concrete vaults utilizing rechargeable filter cartridges which can hold a variety of filter media. An assortment of patented and commercial filter media is available to effectively remove high levels of stormwater pollutants. The appropriate media are selected based on the pollutants expected at the site. The StormFilter™ offers the flexibility of changing to different media if actual pollutant loadings/concentrations differ from expectations.

System configurations include the Precast StormFilter™, the Cast-In-Place StormFilter™ and the Linear Storm Filter™. The precast and linear models utilize pre-engineered precast concrete vaults for ease of design and installation. The precast units can come with traffic-bearing lids for placement in parking lots where they take up virtually no land space. The cast-in-place filters are customized units for larger flows and may be either covered or uncovered underground units.

The StormFilter™ is designed to be especially effective for the treatment of high pollutant concentration flows, and particularly those storms early in the rainy season. In general, the StormFilter™'s efficiency is highest when pollutant concentrations are highest (Lenhart, 1998).

How It Works

The filters work by percolating stormwater through the cartridges containing filter media. The media trap particulates and adsorbs materials such as dissolved metals and hydrocarbons. Surface scum, floating oil and grease are also removed, After passing through the filter media, stormwater flows into a pipe manifold cast into the floor of the vault to an open channel drainage way.

The typical precast StormFilter™ configuration shown in Figure 1 consists of an inlet bay with flow spreader, cartridge bay containing the flow cartridges, an overflow and outlet bay (above outlet).The inlet bay serves as a grit chamber and provides for flow transition into the cartridge bay. The flow spreader provides for the trapping of floatables, oils, and surface scum prior to entry into the cartridge bay. Stormwater enters the cartridge bay through the flow spreader, cascades over an energy dissipater and begins to pond. The StormFilter™ is also designed with an inline overflow which operates when the inflow rate is greater than the flow capacity of the cartridges.

Filter Cartridge Hydraulics

Each cartridge plugged into the underdrain manifold is about 19" tall and 19" in diameter and designed to treat a flow of 15 gpm with 2.3 feet to total system head.

Once stormwater begins to pond in the vault cartridge chamber, it percolates through the media and begins to fill the center drainage tube. As the center drainage tube fills, the air is purged out the one way air relief valve located in the filter top. Once the tube is filled with filtered water, there is enough buoyant force on the float to lift it from its seat. The filtered water is then allowed to flow out of the cartridge into the drainage manifold. As the column of water moves down, the air valve snaps shut and primes a hanging column of water. The hanging column of water then draws the stormwater horizontally through the media and into the inner drainage tube with about 18 inches of suction head.

The filter cartridge (Figure 2) will continue to draw water throughout the storm duration. At some point during the storm, the outflow rate from the filter will exceed the inflow rate and the water surface elevation in the vault will begin to drop. This will continue until the water surface reaches the lower lip of the hood. At that point the suction head will violently draw air into the hood causing high energy turbulence between the inner surface of the hood and the outer surface of the filter media.

This high energy turbulence scrubs much of the accumulated sediments from the surface of the filter causing 1) a high concentration suspension which then settles, or 2) a direct sloughing of sediment to the vault floor. Sediments

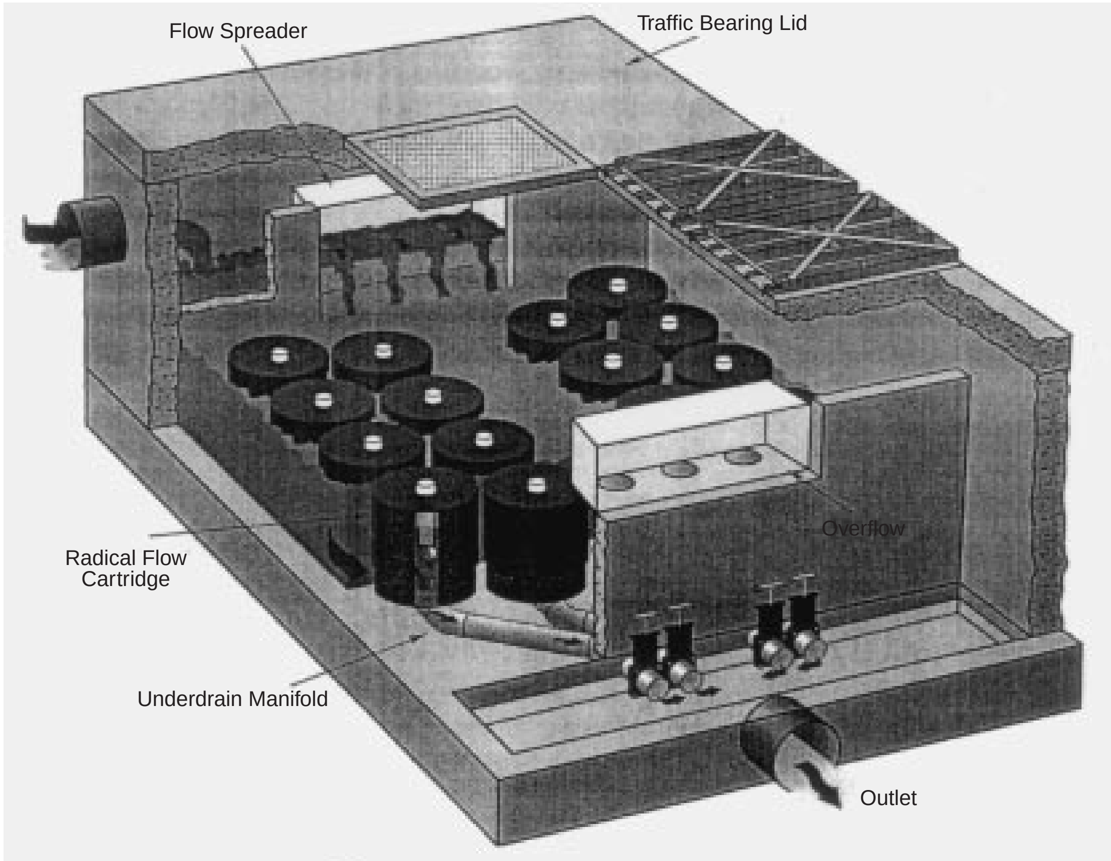


Figure 1. Precast StormFilter™ diagram.

don't get into the underdrain area because all water arriving there has been filtered. This scrubbing action will partially restore the permeability of the filter thus enhancing its performance by increasing the filter life and decreasing filter maintenance frequency and costs.

The Drainage Manifold

The drainage manifold is a pre-manufactured pipe system that is shipped to either a concrete precaster or cast-in-place concrete contractor. The manifold consists of a series of 3"x2" tees on equidistant spacing with control valves at the outlet. The control valves automatically regulate flow to 15 gpm per cartridge. The manifold is secured in place according to plan and cast into the floor of the facility (Figure 3). The removable cartridges are then “plugged” into the manifold tees.

Basic System Design

The StormFilter™ is sized to treat the peak flow of a design storm. Peak flows are typically determined by calculations based on the contributing watershed hydrology and using a design storm magnitude. The design storm is usually based on the requirements set by the local regulatory agency. The size of a StormFilter™ is determined by the number of filter cartridges required to treat the peak stormwater flow.

Each cartridge is designed to treat a peak flow of 15 gpm (or 30 cartridges/cfs). For example: a peak design stormwater flow rate of 150 gpm would require 10 cartridges. The StormFilter™ typically requires 2.3 feet of head differential between the invert of the inlet and the invert of the outlet.

Depending on individual site characteristics, some filters are equipped with high and/or low flow bypasses. High flow bypasses are installed when the calculated peak storm event generates a flow which overcomes the overflow capacity or design capacity of the filter. Base flow bypasses are sometimes installed to prevent continuous inflows caused by ground water seepage.

Available Filter Media

CSF® Leaf Compost Media

In autumn deciduous trees begin to drop their leaves in preparation for the winter. In metropolitan areas the leaves accumulate, clog storm drains, and may cause local flooding. To prevent this, many cities have leaf collection programs. Leaves are either swept up or brought to drop-off points and then transported to landfills, or municipal or commercial composting facilities.

Using a feed stock of pure deciduous leaves (i.e., no mixed yard debris such as prunings and grass), Stormwater

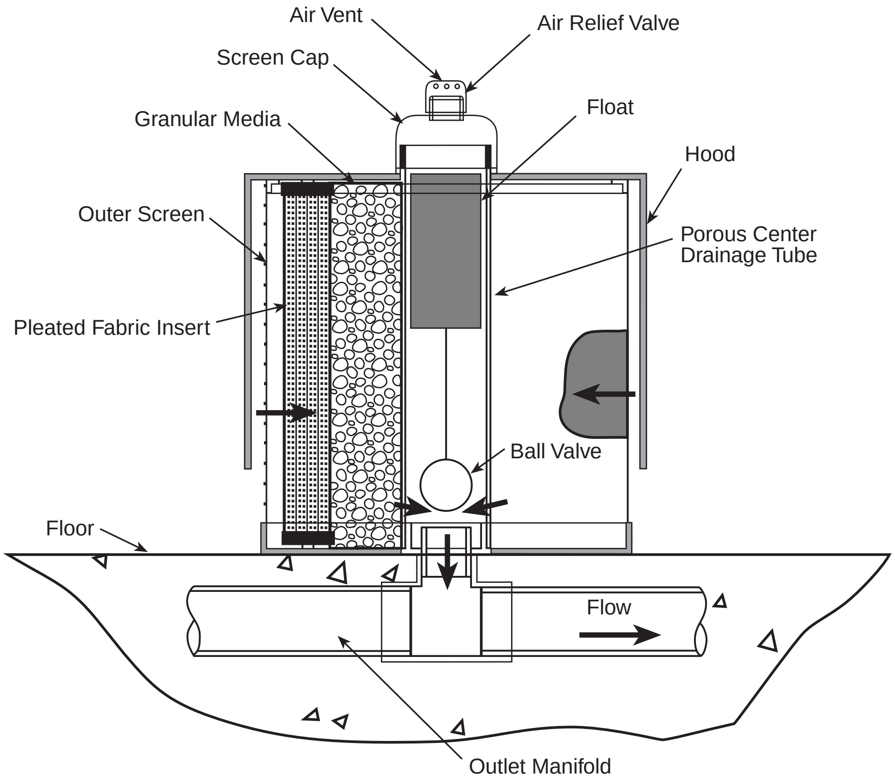


Figure 2. Filter cartridge.

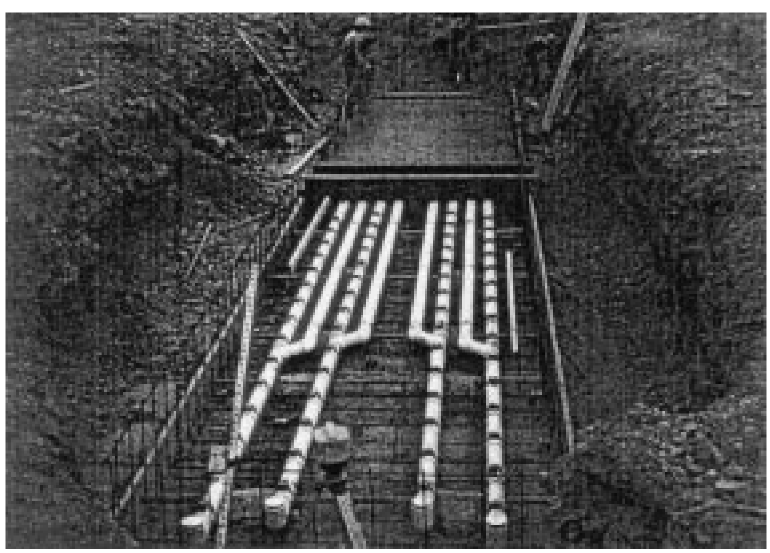


Figure 3. Casting the pipe manifold into the floor of this cast-in-place vault.

Management composts leaves collected by the City of Portland, OR, over a period of eight months into a mature stable compost. Stormwater Management then processes the finished compost into a granular media which resembles soil and has no odors. Once complete, the medium appears to have the physical and chemical characteristics desirable for the filtration of stormwater.

Pollutant Removal Mechanisms

There are three primary pollutant removal mechanisms performed by the CSF® filter media: mechanical filtration to remove sediments, chemical processes to remove soluble metals, and adsorption properties to remove oils and greases.

Sediments

The media are contained in a series of filter cartridges which have a 7" thick layer of the media through which stormwater passes. Sediments are filtered out on both the surface of the filter and the surfaces of granules throughout the media matrix. As sediments are removed from stormwater runoff and accumulate on the surface of the filter, the permeability will decline thus requiring facility maintenance. Sediment removal will vary with particle size distribution, but removal has been as high as 95%.

Soluble Heavy Metals

The media also acts as a chemical filter to remove dissolved ionic pollutants such as soluble heavy metals, including lead, copper, and zinc. The mechanism of cation exchange is provided by humic acids, which are produced by the aerobic biological activity which occurs during composting. Soluble heavy metal removal rates vary from 65% to 95%.

Oils & Greases

Removal of oils and greases (O&G) and other organic compounds is facilitated by the high organic carbon content of the media. The organic carbon is oleophilic and adsorbs free oil and grease. The system performs best when O&G loadings are less than 20 mg/l. Measured removal rates are as high as 80% (W&H Pacific, 1992).

Pleated Fabric Inserts

The pleated fabric insert is used primarily for sediment control (Figure 4).The insert fits inside the standard cartridge leaving an annular space between the inside of the insert and the drainage tube, which can be used for the addition of granular media to remove selected soluble pollutants.

The reusable insert is constructed of a durable fabric which is easily cleaned with low-pressure water. Each insert has a total of 75 square feet of surface area. Two fabric pore sizes of 70 microns and 36 microns are available. Sediment loading performance data for the two fabrics, using granular media only, are presented in Graph 1.

The CSF® media showed a 50% decrease in flow rate after the accumulation of 12 pounds of dry sediment per cartridge. The 70 µm fabric filter insert prolongs the permeability of the system by three times over media alone and the 36 µm fabric increase the life by a factor of two. As shown by the 50% flow rate decrease line, it would require 23+ pounds of sediment per cartridge to slow the flow rate of the 36 µm fabric to 7.5 gpm and 31+ pounds per cartridge for the 70 µm fabric.

Graph 2 shows the particle size distribution of the sediments used in these tests. TSS removal by the fabric filters is 100% of particles over 36 µm, and some portion of particles under 36 µm (The sediments were taken from existing stormwater quality facilities, dried and screened through a #45 mesh).

Also note on Graph 1, the abrupt jumps in flow rate. These jumps represent the flow recovery generated by the self cleaning mechanism. Once the jump occurred, the sediments that settled to the bottom were intentionally resuspended during testing to ensure that 100% of the sediments used were attached to the filter surface.

Table 1 presents estimated volumes of water treated as well as the approximate dry sediment poundage that a typical 8' x 14' StormFilter™ containing 18 cartridges could treat and capture respectively.

Values in Table 1 assume TSS = 75 mg/l, sediment composed of 50% fine sand and smaller particles, and an 8' x 14' StormFilter™ containing 18 cartridges. The values also assume the removal of 100% of suspended solids with no sediment accumulation at the bottom of the vault.)

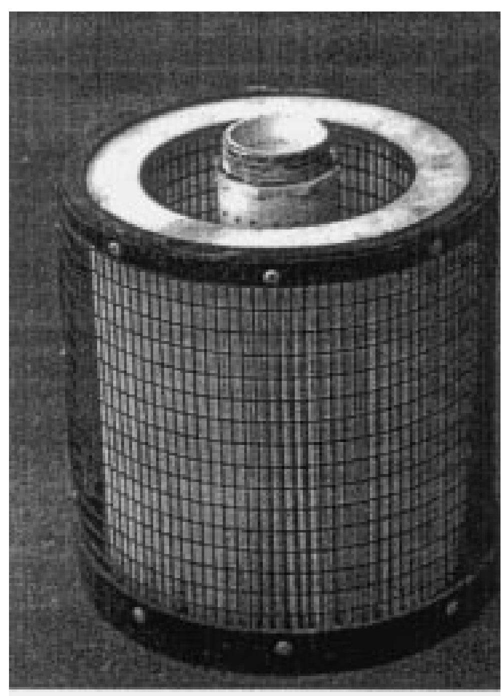
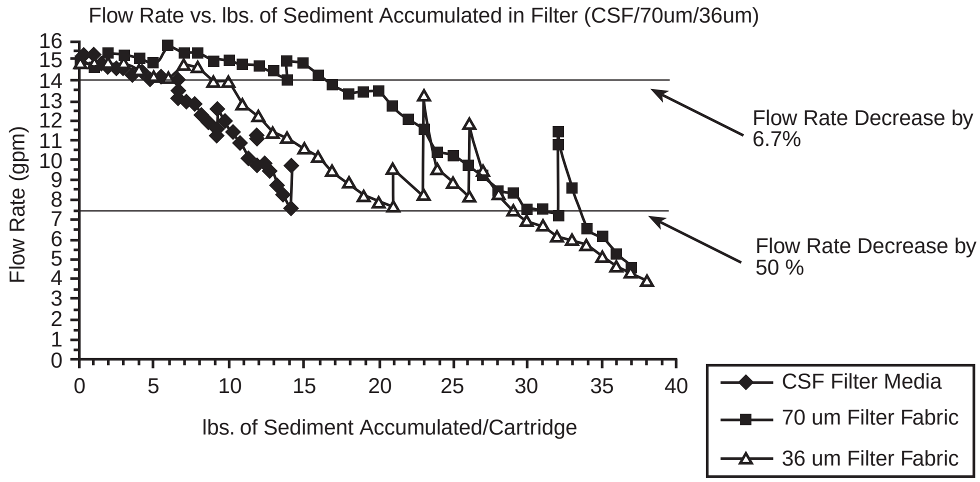
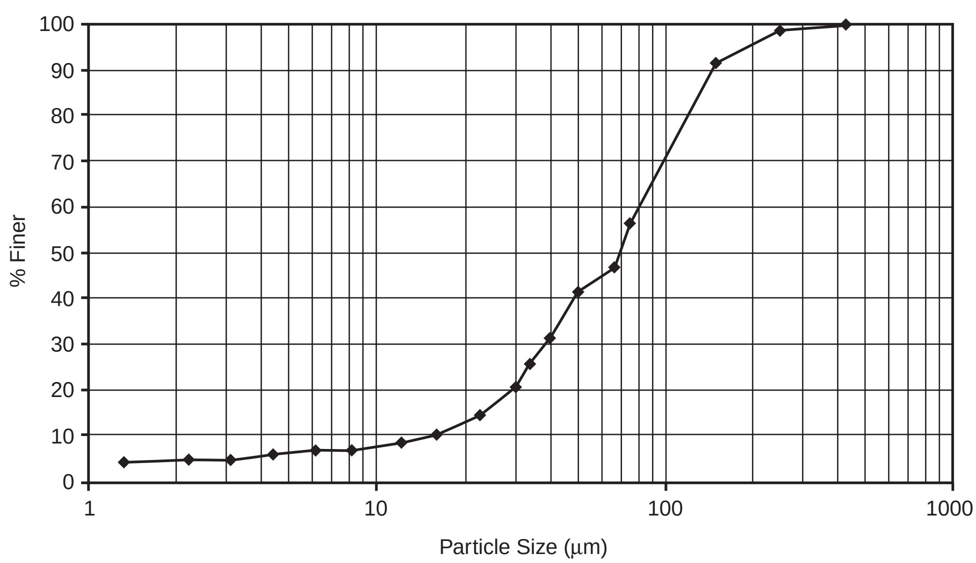


Figure 4. Pleated fabric inserts.



Graph 1. Sediment accumulation reduces flow rates.



Graph 2. 1997 185th particle size distribution.

Table 1. Predicted Sediment Removal Rates

	CSF® Media	36 micron fabric	70 micron fabric
6.7% Decrease (decrease from 15 to 14 gpm)	115 pounds sediment	200 pounds sediment	310 pounds sediment
	180,000 gal. water	320,000 gal. water	500,000 gal. water
50% Decrease (decrease from 15 to 7.5 gpm)	260 pounds sediment	425 pounds sediment	560 pounds sediment
	409,000 gal. water	680,000 gal. water	892,000 gal. water

If the designer knows the maximum allowable decline in system efficiency and the system is designed for the 15 gpm/cartridge, the graph and table can be used to establish the total sediment loading that occurs between maintenance cycles. (More water has passed through filters when their permeability has decayed to 50% than when it has decreased by only 6.7%.)

Perlite and Zeolite Media

Perlite is a "puffed" volcanic ash. This lightweight material is commonly used as a filter for water filtration. Though not chemically active, Perlite is very effective for removal of fine particles due to its micro pores and blocky structure. Perlite can be used as a stand alone medium or in conjunction with the pleated fabric insert. Perlite can also be mixed with other media such as Granulated Activated Charcoal (GAC), commercial cation exchange media, etc. Perlite would inexpensively act on TSS while GAC, etc. would act on organics.

Zeolites are naturally occurring minerals that exhibit cationic exchange properties. Some zeolites have the capacity for anion adsorption. Blended perlite/zeolite media produced by Stormwater Management is suggested for watersheds where soluble phosphorus is of concern.

To demonstrate the removal efficiency of phosphate by the zeolite, 2-inch column studies have been performed with a varying matrix of zeolite mixed with a highly permeable perlite. The tables below present the data obtained from several column studies and show the percent removal of ortho-phosphate promoted by the zeolite. (Each table is followed by a brief description of the sample number and sample time.) The influent source was irrigation return water from a commercial container nursery.

The samples labeled 10G-1 and 30G-1 represent the first effluent samples taken from a 10-gram and 30-gram column test respectively. These samples were taken after approximately 100 ml of stormwater had passed through each 2-ing diameter column. The samples labeled 10G-2 and 30G-2 represent samples taken after approximately 1000 ml of stormwater had been passed.

Table 2. Ortho-Phosphate Removal

Sample	Influent	Sample 10G-1	Sample 10G-2	Sample 30G-1	Sample 30G-2
Ortho-P (mg/l)	0.33	0.18	0.25	0.15	0.18
% removal		45.4%	24.2%	54.5%	45.4%

Tables 3, 4, and 5 represent preliminary testing of phosphate (at three concentrations) removal.

Table 3. Ortho-Phosphate Removal

Sample	Influent	Sample 40.3	Sample 40.5
Ortho-P (mg/l)	0.37	0.20	0.32
% removal		49.5%	13.5%

The sample labeled 40.3 represents a composite sample of the first 4 gallons of effluent passed through 40 grams of zeolite with the 40.5 sample being the 5th gallon passed.

Table 4. Ortho-Pohsphate Removal

Sample	Influent	Sample 50.1	Sample 50.3	Sample 50.5
Ortho-P (mg/l)	0.38	0.15	0.34	0.36
% removal		60.5%	10.5%	5.3%

The samples labeled 50.1, 50.3, and 50.5 represent samples taken of the 1st gallon, the 3rd gallon, and 5th gallon of effluent respectively.

Table 5. Ortho-Phosphate Removal

Sample	Influent	Sample 60.5
Ortho-P (mg/l)	0.37	0.19
% removal		48.6%

The effluent sample labeled 60.5 represents a combination of the entire 5 gallons of stormWater passed through the column.

Though further studies are underway, these data indicate a sorbtive capacity of 60 mg ortho-phosphate/kg of zeolite media. We expect to achieve double that removal rate soon. Depending on the mass concentration of zeolite in the media, one is able to estimate the mass removal of ortho phosphate between filter maintenance cycles.

Facility Maintenance

The primary purpose of the StormFilter™ is to filter out and prevent pollutants from entering down gradient water bodies. Like any effective filtration system, these pollutants must be periodically removed to restore the StormFilter™ to its full efficiency and effectiveness. Maintenance requirements and frequency are dependent on the pollutant loading characteristics of each site. To assist with maintenance issues, detailed Operation & Maintenance Guidelines are available.

Maintenance services can be purchased completely, or in part. Stormwater Management also provides tracking of all installed systems, notifies system's owner of maintenance needs and notifies the regulatory agency that the system has been maintained.

Maintenance is usually performed late in the dry season to rejuvenate the filter media and prepare the system for the next rainy season. Maintenance activities can also be performed mid-season in the event of a spill or excessive sediment loading due to site erosion.The most common maintenance schedule is once a year, but sites can and do vary.

Maintenance involves replacing the cartridges with a series of newly recharged cartridges. The old cartridges are then cleaned and recharged with new media for reuse. Systems with excess sediment accumulation on the vault floor can be vactored out.

Media residuals can be re-composted to reduce accumulated hydrocarbons and then used in landscaping, erosion control applications or daily cover for landfills. This sustainable process helps minimize total maintenance costs.

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Bioretention: An Efficient, Cost Effective Stormwater Management Practice

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Abstract

In 1993 the Department of the Environmental Resources, Prince Georges County, Maryland, introduced the "Design Manual for Use of Bioretention in Stormwater Management". Bioretention facilities have become commonly referred to as rain gardens. They were designed as an alternative, cost effective stormwater best management practice (BMP) which allows multifunctional use of green space and landscaped areas for storage and treatment of runoff. Bioretention BMPs are simply very shallow landscaped depressions where runoff is infiltrated or filtered through a soil/plant complex for treatment. Bioretention has been successfully used as an alternative, cost-effective BMP for commercial, industrial and residential applications addressing both landscape and stormwater management objectives. More recently, as a retrofit practice, the BMP has been incorporated into green space, streetscapes, median strips and parking lot islands. This paper summarizes recently completed monitoring findings and the lessons learned over the last five years with the use of bioretention for urban stormwater management.

General Bioretention Design Features

Bioretention was originally modeled after the hydrologic/ physical characteristics of an upland terrestrial forest or meadow community (as opposed to a wetland) dominated by facultative trees, with understory shrubs and herbaceous upland plant materials. The BMP is strategically placed to intercept drainage and is therefore, subject to repeated hydraulic loading. Because of this, the designer must be sure that the BMP will be well drained to maintain aerobic conditions. Proper drainage can be achieved by infiltration (where soils allow), underdrains, or both. Key factors in the design and construction of bioretention facilities are careful selection of plant material that can tolerate extreme hydrologic regimes; good drainage to prevent anaerobic conditions; safe conveyance of overflows; careful selection and control of backfill soils; and, careful inlet/ outlet controls to prevent erosion.

Bioretention BMPs should be designed as "off-line" control devices where excess runoff and high-velocity flows bypass the BMP minimizing erosion and flushing of landscape materials and debris. Stored runoff (ponded water over the bioretention area) should exfiltrate over a period of less than a day into the underlying soils and in some cases, into an underdrain that discharges to an appropriate conveyance system. Where soil infiltration rates are lower than 1 inch/hour, or in order to extend the life of the facility, underdrains should be used.

Bioretention areas typically consist of the following components: shallow ponding area (6" or less), mulch layer (2-3"), sandy planting soil (2-3'), a variety of plant materials and where appropriate underdrains. The design of the BMP can vary greatly to accommodate site constraints, ground water recharge, soils, habitat/ecological objectives, watershed hydrology and aesthetics. The freedom in design variation creates opportunities for site integration of natural features with man-made infrastructure. Specific configuration and location is determined after site constraints such as location of utilities, groundwater level, steep slopes, underlying soils, existing vegetation and drainage are considered.

The drainage area for one facility should generally be between 0.25 and 1 acre. Multiple bioretention facilities are needed for larger drainage areas. The storage volume of the facility will be determined by the desired level of control (e.g. first half-inch of runoff) and dewatering capabilities of the design. The BMP works best when there are many facilities with small drainage areas. Large facilities with large drainage areas tend to allow soils to remain saturated creating anaerobic conditions, stressing the plants and potentially reducing the pollutant removal effectiveness for many pollutants.

Planting soil should be sandy loam, loamy sand or loam texture and have clay content of 10% to 15% or less. The pH of the soil should be between 5.5 and 6.5 to maximize plant growth and microbial activity for the up-take and transformation of pollutants. The planting soil should contain 3 to 5% organic content and other soil augments typically needed to support the types of plants used.

Native plant species are recommended as they are generally more suited to regional climate, soils, hydrology, and disease. The designer should assess aesthetics, site layout, habitat objectives and maintenance requirements when selecting plant species. After placing the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses, legumes or flowers can be used. Two or three inches of commercially available fine shredded hardwood mulch or shredded hardwood chips should be applied to provide protection from erosion, as well as to enhance evapotransporation in the facility.

Monitoring

In an effort to refine bioretention design and determine the pollutant removal efficiency of the BMP, a two-year study was conducted by the University of Maryland, in conjunction with Prince George's County, Department of Environmental Resources and the National Science Foundation. The study, known as the "Optimization of Bioretention" and included both laboratory and field testing.

The laboratory experiments were conducted in two small (3 ft x 2.5 ft x 2.5 ft deep) and one large (10 ft x 5 ft x 3.5 ft deep) bioretention "boxes". These boxes were filled with a sandy loam soil topped with a 1-inch layer of commercially available shredded bark mulch and planted with creeping junipers. Perforated pipe sampling ports were placed at three depths (upper, middle and lower) within the larger box to examine pollutant removal as a function of depth and time of exposure. Two sampling depths were used for the smaller box. Effluent samples were analyzed in the University of Maryland's Environmental Engineering Laboratory.

A synthetic runoff recipe was used for all testing to allow for greater consistency and correlation of field and laboratory results. The runoff recipe was based on the average pollutant loading taken from the county's 3-year wet weather data collected as part of the NPDES stormwater monitoring program. The hydraulic loading or rate of application to the bioretention facilities was based on a typical rainfall event in Prince Georges County (0.1 in/hr with a 6-hr duration).

Average removals in the laboratory bioretention systems are shown in Table 1. Sample contamination resulted in no nitrate data for the small boxes. In both cases, removal of the heavy metals (copper, lead, and zinc) was excellent, ranging from 93-99%. Effluent levels of phosphorus showed 70-80% removal. Average TKN and ammonia removals were 60-80% in the lower effluent ports, but significant ranges were noted for each. The system removed only a small amount of the nitrate (23%) and nitrate concentrations above the influent levels were noted from the upper ports.

For the small bioretention boxes, flow from the bottom began approximately 45 minutes after the runoff application. It took about 2 hours for flow to occur from the bottom ports in the large box. In both boxes, the head built up to 3-5.5 inches.

Field Experiment

Field monitoring was performed on an existing bioretention facility. This facility was constructed with an underdrain at a depth of about 2.5 ft., which was used for the sampling port. The same runoff pollutant "recipe" was applied in the field. The runoff application continued for nearly six hours with samples taken every 25-30 minutes.

Results from the field experiment mirrored the laboratory results. For copper, lead, and zinc, nearly total removal was achieved by the bioretention facility with removals exceeding 95%. All metal concentrations in the effluent were less than or near instrument detection limits (2 mg/L for copper and lead, 25 mg/L for zinc). The total phosphorus removal was about 60%. TKN removal was about 50%. The ammonia removal was somewhat variable but the majority of the samples monitored indicate about 70% removal. The removal for nitrate was only about 15% with wide variation.

Summary of Monitoring Observations and Findings

Heavy metal removal showed excellent agreement between the field and laboratory experiments. Removals were

Table 1. Summary of Percent Removal Rates for Laboratory Bioretention Systems

	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	P (mg/L)	TKN (mg/L)	NH_4^+ (mg/L)	$N0_3^-$ (mg/L)	TN (mg/L)
Large Box								
U	90	93	87	0	37	54	(-97)	(-29)
M	93	99	98	73	60	86	(-194)	0
L	93	99	99	81	68	79	23	43
Small Box								
U	91	95	93	16	55	(-7)	-	-
L	97	98	97	70	76	60	-	-

Testing Conducted by the University of Maryland, Department of Engineering greater than 90% and variations were small. Nearly the entire metal uptake occurred within the top few inches of the bioretention system. Separate small column laboratory experiments with the mulch showed that it has a high capacity for metals uptake. It is likely that within bioretention facilities, significant metal uptake occurs within the surface mulch layer. Additionally, examination of the laboratory bioretention mulch after several applications of the synthetic runoff showed elevated metal levels. All results point to the importance of the mulch layer for metals uptake in bioretention.

Phosphorus removal appears to have linear correlation to depth, with better removal resulting as runoff migrates to deeper levels. Limited additional removal was observed beyond depths of about 2 to 3 feet.

TKN removal averaged about 60% with significant variability. The depth of the facility does not appear to significantly affect TKN removal rates.

Ammonia removal appears to increase to over 70% at greater depths. However, due to significant variation in results, depth correlation is difficult to summarize.

Nitrate removal results were erratic and significant variability was found. Shallow sampling ports showed nitrate levels higher than the input, indicating conversion of organic nitrogen, or ammonia to nitrate during the runoff event, or washout of nitrate from previously captured nitrogen. At depths greater than 30 inches, limited nitrate removal occurred (15-20%).

Additional research is needed to optimize the pollutant removal/transformation capabilities of the plant soil complex. It appears possible that the chemical make-up of the soil complex and the types of plants used for bioretention can be customized to address unique pollutant runoff problems and recharge needs for a given land use and watershed.

Bioretention Design & Construction Considerations Based on Monitoring Results

Laboratory and field studies, along with field observations over the last five years have provided data necessary to refine bioretention design and construction criteria. Modifications to the Prince Georges County bioretention design manual are currently underway based on these findings. Some of the major modifications are listed and briefly described below:

Optimizing Facility Depth - The original design depth was set at 4 feet. This was to ensure adequate depth for plant growth and to maximize pollutant removal. The experiments performed to date suggest that sufficient removal is achieved at a 2 -2.5 foot depth. Therefore, design depths can be reduced without significantly compromising pollutant removal efficiency. This will result in cost savings by reducing excavation and back-fill material costs. Underdrains are recommended for all facilities unless geotechnical reports indicate otherwise.

Minimizing Above Ground Storage Depth - Above ground storage of runoff is necessary to achieve retention storage for treatment and management of stormwater runoff. However, the depth of the runoff should be minimized to allow quicker infiltration and evapotranspiration. This will ensure adequate aeration of soils to maintain aerobic conditions necessary for plant growth and various pollutant transformation processes. The recommended maximum ponding depth is 3-6 inches per facility.

Minimizing Hydraulic Loading - The drainage area for bioretention BMPs should be minimized to reduce hydraulic loading of the facility and avoid excessive saturation of the soils which could lead to anaerobic conditions. The maximum recommended drainage area is 1 acre. Ideally, facilities should be designed to control 0.25 acres or less if site/soil conditions and land use allow.

Planting Soil and Soil Amendments - Soil amendments are only necessary for plant viability. The planting soils should have no greater than 10-15% clay particles. Soil infiltration rates of greater than 1 inch an hour are preferable if no underdrain system is used. Native plants require less maintenance.

Facility Sizing and Configuration - Sizing of the facility is dependent upon the drainage area, land use and site constraints. On-lot facilities are limited to space available and grading. As previously indicated, facilities may have soil depths of 2 feet and still achieve significant pollutant removal rates. In addition, the side walls do not need to be straight up and down, but can be shaped in a “dish arrangement” beginning at the ground level around the perimeter and extending to a the design depth in the center. All facilities should be “off-line” to avoid pass-through waters that could cause erosion and flushing of debris from the facility unless carefully designed to accomodate these effects.

Settlement and Compaction- During construction, due to the nature of the planting material and method of installation, settlement will occur. In the University Maryland experiment, 15-20% settlement of the soil was observed after the first influent was applied. Interestingly, after the initial settlement, only minor settlement was reported. In construction, settlement is a concern particularly for the accuracy of final grading and volume storage. Settlement has implications related not only to construction method, but cost as well. To help control problems created by differential or unexpected settlement, wetting of the planting soil prior to placement of mulch and plant materials is recommended. This can be accomplished by hosing down the area (or if time permits, waiting for a rain event). Compaction of the soils must be minimized during construction activities. Bioretention facilities that are shallow (2-3’) can be constructed and dressed using manual labor and small machinery.

Planting Arrangements- Planting arrangements are important for aesthetics, soil stability, habitat, pollutant uptake and the viability of the bioretention facility. Initial planting arrangements should be designed to provide an immediate dense and perpetual ground cover. For example, use of ornamental grasses provides thick, quick growing cover and uptake of pollutants. Facilities located in areas of high visibility should include plant material that is aesthetically pleasing with year-round interest. The use of native planting arrangements is encouraged. Designers should work closely with landscape architects and nurserymen to plan an aesthetically pleasing, yet cost conscious product. Plant materials and landscaping can affect the cost of the facility dramatically accounting for as much as 60% of the total facility cost.

Designing for Thermal Attenuation - Thermal pollution in runoff to receiving waters has been correlated to increases in urban development. Heated runoff temperatures from impervious surfaces is one of the main causes of elevated stream temperatures. By directing and capturing heated runoff into a bioretention facility to allow evaporation, infiltration and filtration into the soil, the facility can act as a heat sink and dissapation. Where protection of cold water fisheries is an important consideration, bioretention can be used to reduce thermal impacts of urban runoff.

Designing for Hydraulic Conductivity - When designing and locating bioretention facilities without underdrains, special attention must be given to the hydraulic conductivity of the surrounding in situ soils. They should have a very high percentage of sand particles (2mm in size or greater) to ensure adequate infiltration. Soils must be USDA classification sandy loam or better in the textural triangle. When performing feasibility analysis for siting bioretention facilities, the hydraulic conductivity of the surrounding soils must be analyzed sufficiently by geotechnical means such as soil borings. Soils investigations typical to the requirements for standard infiltration trenches can be performed to determine the suitability of the in situ soils. Soils having a significant percentage of small soil particles can lead to failures. In addition, even where boring samples indicate small percentages of clay, the soils analysis should determine the makeup of the soil strata and horizons to ensure that clay lenses are not present.

Bioretention Applications

Bioretention systems maximize the use of natural physical, chemical and biological pollutant removal and transformation processes to treat runoff. They are dynamic living micro-ecological systems that demonstrate how the landscape functions to protect the integrity of a watershed's aquatic and riparian ecosystems. Their designs also demonstrate the interconnections of a wide array of environmental and engineering principles and disciplines including: the hydrologic cycle, nonpoint pollutant treatment, nutrient cycles, resource conservation, habitat creation, soil chemistry, ecology, horticulture and landscape architecture.

Bioretention systems use upland facultative plants that are not dependent on a constant source of water such as conventional stormwater /wetland ponds. Therefore, bioretention systems can be constructed in the upland areas avoiding destruction of riparian buffers and streams. Typically, upland soils are more conducive to the natural properties that bioretention facilities are attempting to mimic. Those same soils often are associated with hydrologic soil groups "A" and "B", which exemplify well drained soils.

Widespread use and uniform distribution of bioretention storage throughout a development can also help to replicate predevelopment watershed hydrologic functions. This BMP can be used to reproduce similar rainfall storage capabilities in the developed site that existing prior to development. Retention and groundwater recharge functions are designed to mimic predevelopment runoff characteristics. Reproducing predevelopment hydrologic functions can be the most important factor in maintaining the ecological integrity of receiving waters, small streams and wetland systems.

To achieve uniform distribution of bioretention practices for the greatest hydrological benefits and to maximize pollutant removal, it is important to understand how to integrate the practice into the developed landscape. Below is a listing and brief discussion of the possible ways to apply bioretention throughout a site.

Incorporated into Parking Lots, Medians and Landscape Islands - The design must ensure that infiltration and ground water seepage will not adversely affect the structural integrity of roadways or buildings. Careful grading, location and use of underdrains can minimize problems. It is important to divert overflows to inlets or grass areas in order to prevent deposits of sediment and debris onto parking surfaces.

Designed into Existing Meadow or Forested Areas - These areas can be converted to rain gardens by constructing small earthen or stone berms (4 inches or less) to allow shallow ponding. Care must be taken not to pond too much for too long, as existing mature vegetation may be less tolerant to drastic changes in hydrology. Also, adequate measures must be taken to reduce erosion potential when directing increased volumes and concentrated flows into existing vegetated areas.

Fringe Forest and Transition Areas - Bioretention can be used for re-vegetation of forest fringe areas to recreate a terrestrial forest community and transitional habitat ecosystem. These areas would consist of trees, sub-canopy under story trees, a shrub layer and herbaceous ground covers. Plants can be selected for their habitat value (food, shelter and nesting materials). Deep rooted vegetation would help to promote increased infiltration.

Open Space Meadows - Open space areas not used for recreation or other purposes can be designed as rain gardens. Where soils and topography allow, wild flower meadow basins can be constructed. Care must be taken to prevent erosion and to disperse flows throughout the bottom of the rain garden basin.

Open Swales - Rain gardens must be carefully designed to be used on-line in an open swale. They may be used as an appurtenance to a swale in an off-line configuration. On-line systems are subject to erosion due to high velocities and concentrated flows without the careful design.

Landscape Trees and Shrubs - A simple application of a rain garden is to create shallow depression storage areas around each individual landscape plant. Careful selection of water tolerant species could allow ponding depths of 2 to 3 inches around each plant where soils allow.

Retrofit Existing Development - Many green spaces and landscaped areas can be converted to rain gardens. The applicability of retrofit options will be dependent on a detailed site evaluation.

Sediment Control - Like stormwater management ponds, bioretention pits may be utilized for sediment control devices for stabilization during construction activities. By using on-lot bioretention for sediment control compliance, the need to drain the site runoff to one large holding pond is eliminated or diminished.

Limitations

Bioretention that relies on infiltration alone for dewatering should not be considered where the water table is within 6 feet of the ground surface and when the surrounding soil is unsuitable for infiltration (less than one inch/hour). While the bioretention concept relies on the natural and physical properties of infiltration, absorption and evapotransporation, these processes can have limited capacity under various conditions such as saturated soil, frozen ground, or high humidity. The practice is also not recommended for areas with steep slopes greater than 25% or in areas where extensive tree removal would be required.

When used on residential lots to fulfill stormwater requirements, property owners must be educated on the need and routine care of rain garden areas. Maintenance agreements, educational materials and easements are possible ways to ensure long term use and operation by the property owner.

General Cost Comparisons

Bioretention costs are most attractive when compared to the use of other structural BMPs such as ponds. Cost savings over conventional BMPs can vary widely depending on unique site conditions. More efficient use of land can be achieved when integrated into the typical landscape features. Savings of 10 to 25% compared to conventional approaches have been achieved using rain gardens in residential and commercial sites. Generally, residential rain gardens will average about $3 to $4 a square foot depending on soil conditions and density and types of plants. Commercial/industrial sites costs can range between $10 to $40 a square foot depending on the density / types or plants and the need for control structures, curbing, storm drains and underdrains. Planting costs can vary substantially and can account for a significant portion of the facility cost. In many cases, bioretention can be an extremely cost-effective practice for controlling stormwater. Replacing traditional piping with gardens to convey flow can lead to substantial savings.

There are additional costs when compared to typical landscaping treatment due to the increased number of plantings, additional soil excavation, backfill material and use of underdrains. The use of a wildflower meadow rain garden to replace open space turf will have higher site preparation and planting costs, but long-term maintenance (mowing) can be reduced to once a year.

Long Term Maintenance Considerations

Rain gardens require routine periodic maintenance (e.g. mulching, plant replacement, pruning and weeding) typical of any landscaped area. No special maintenance equipment is needed. Routine maintenance costs will increase proportionately to the increased number of plants used and the area planted. To date, there is no solid data on the longevity of bioretention systems. The use of underdrains will help to ensure the BMP remains well drained for the long term health of the plants. Underdrains placed at shallow depths (2 to 3 feet) can be easily maintained if clogged by sediment or roots.

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Innovative Stormwater Treatment in Washington State

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Introduction

The Washington State Department of Transportation (WSDOT) has a long history of engineering innovation. WSDOT built the first floating concrete pontoon bridge in the world. Other firsts have been achieved in avalanche control and de-icing treatment.

Not every new technology works as theorized. New systems often need to be fine tuned before they can become a standard practice. Innovative Best Management Practices (BMPs), a continuation of WSDOT's engineering innovation tradition, provide design engineers with more appropriate and effective stormwater treatment options. An innovative BMP is one that has not been approved by the Washington Department of Ecology, our state environmental regulatory agency.

WSDOT maintains a Stormwater Management Program (SWMP) to protect water quality through the National Pollutant Discharge Elimination System (NPDES) municipal permit requirements. The permit requires WSDOT to:

- Reduce and control discharge of pollutants to the maximum extent practicable, as required by federal regulations;
- Use all known, available, and reasonable methods of prevention, control, and treatment.

Innovative BMP research is a critical element of our Stormwater Management Program. State and local governments rely on WSDOT to protect and maintain existing water quality. WSDOT does this by using BMPs.

Standard BMPs

WSDOT's Highway Runoff Manual (HRM) provides uniform technical stormwater management guidelines for our highway designers and other stormwater professionals. Stormwater treatment is required when 5,000 square feet of new impervious surface is added to the highway foot print. Design guidelines for standard BMPs are in the HRM and are approved by the Department of Ecology. They include: biofiltration swale, wet pond, infiltration pond, wet vaults, and nutrient control wet ponds.

Innovative BMPs

Oftentimes design and hydraulic engineers cannot select standard BMPs because:

- Technology is constantly changing and the science of stormwater treatment is advancing.
- There is a need to comply with more stringent local requirements.
- Space is limited and expensive.
- Land is not available to install a conventional BMP.
- Land has slope, soil, or light problems.
- A specific water quality need is required which a standard BMP can not satisfy.

These limitations have created a need for more adaptive and effective BMPs. WSDOT has responded by developing an Innovative BMP Development and Research Program. After an innovative BMP performance has been verified and accepted by the Department of Ecology, the BMP will be added to the HRM — if it performed successfully.

Documenting Innovative BMP Performance

Monitoring innovative BMP sites provides valuable performance data. WSDOT's Stormwater Management Program defines our stormwater research protocols and procedures. The SWMP can be downloaded through the

Internet from WSDOT's WEB page. WSDOT has determined that the primary pollutants of concern that are representative of highway runoff are:

Solids:	Total Suspended Solids	Total Dissolved Solids
Metals:	Cadmium (total) Copper (total) Lead (total) Zinc (total)	Cadmium (dissolved) Copper (dissolved) Lead (dissolved) Zinc (dissolved)
Oxygen Demand:	Biochemical Oxygen Demand (5 day)	Chemical Oxygen Demand
Nutrients:	Phosphorous (total) Orthophosphates	Nitrate-Nitrogen

These stormwater constituents will be analyzed routinely at our research sites. On a semi-annual basis, WSDOT performs priority pollutant scans which include polynuclear aromatic hydrocarbons, ultimate (20-day) biochemical oxygen demand, and effluent toxicity using the Microtox™ technique.

Vegetated Filter Strip

Research Objective

Vegetative filter strips currently exist along many of our rural highways; however, they are not considered a standard BMP by the Department of Ecology. The research objective is to gather the needed data to demonstrate that a vegetative filter strip should be accepted as a standard BMP in our HRM and under what conditions. Three test filter strips are being evaluated at our SR 8 Black Hills research site in Thurston County.

Design

Vegetative filter strips are planned for use in rural areas on state highways. The average daily traffic count at these sites does not exceed 30,000 vehicles per day. Vegetative filter strips run parallel to the roadway, and runoff from the roadway flows off of the roadway, across the shoulder and then across and into the vegetative filter strip. Typically filter strips are 15 feet wide and 2 to 4 feet from the edge of the pavement.

Figure 1 shows a filter strip BMP plan view site layout of a facility which was built in January 1996. The slot drain serves as the control for runoff volume and pollutant constituents. Three different soil matrixes are evaluated at the research facility, including commercially available compost, organic-rich soil from a local river bottom, and the existing rock and soil that was excavated (or road-Ex) at the research site. Each filter strip was hand seeded with Mechlenberg Fescue.

The facility design allows the amount of runoff moving across and into each filter strip to be monitored, as well as to determine the pollutant removal performance. Because each filter strip was lined with a clay liner, a water balance can be performed. To differentiate between surface overflow and flow through the filter strip, perforated drain pipes were installed at the top and at bottom of each filter strip. The drain pipes are separated by an impervious layer to prevent cross-flow.

Preliminary Results

Data have been collected for twelve storm events over two years. Data will continue to be collected for an additional year. Washington State University evaluates the data and prepares a report.

Preliminary results demonstrate that compost fill may provide stormwater detention as well as treatment. The compost soil matrix captured and held the stormwater; only a small proportion of the total storm event flowed through the compost media. No surface overflow was recorded in any storm event.. The data also show that composted material initially releases nitrogen and phosphorus into the discharge water. This may be a concern in watersheds with sensitive lakes.

The organic soil matrix allowed about half of the runoff to sheet flow over the filter strip and the other half to infiltrate through the soil matrix. The road-Ex soil allowed more than 80% of the runoff to sheet flow over the filter strip and less than 20% of the runoff to infiltrate through the filter strip.

The grass grew best on the compost soil, followed by the organic-rich top soil. Grass grew the poorest on the road-Ex. Because of poor seed germination in the organic-rich soil and road-Ex, grass seed and water was reapplied on three separate occasions. Runoff and infiltration rates were directly related to grass growth. Increased infiltration was observed as grass growth improved.

Difficulties

Accurately recording the discharges through the system was very difficult. Runoff volumes were too small to get a measurable head in the smallest (0.4 HS) commercially available flume. On the other hand, runoff was too large to contain in a single container. In addition, runoff and infiltration ratios varied widely from each filter strip. It was also very difficult to use commercially available flow-proportionate samplers to collect samples for water quality analysis. Through many trials and disappointments, we finally were successful with:

source	quantity measurement	quality measurement
slot drains (control sample)	0.4 HS flume in conjunction with ISCO 3700 samplers	flow proportioned samples using ISCO 3700 samplers
overflow	nutating disk meter	"in-line sampler"
under flow	nutating disk meter	"in-line sampler"

For locations where using automated samplers proved to be ineffective, an in-line sampler was devised to obtain flow proportionate samples. The in-line sampler conveys the flow through a one-inch diameter pipe and across an irrigation drip valve. Vinyl tubing attached to the drip valve conveys a small proportion of the total flow to a plastic bucket. The angle of the drip valve controls the amount of

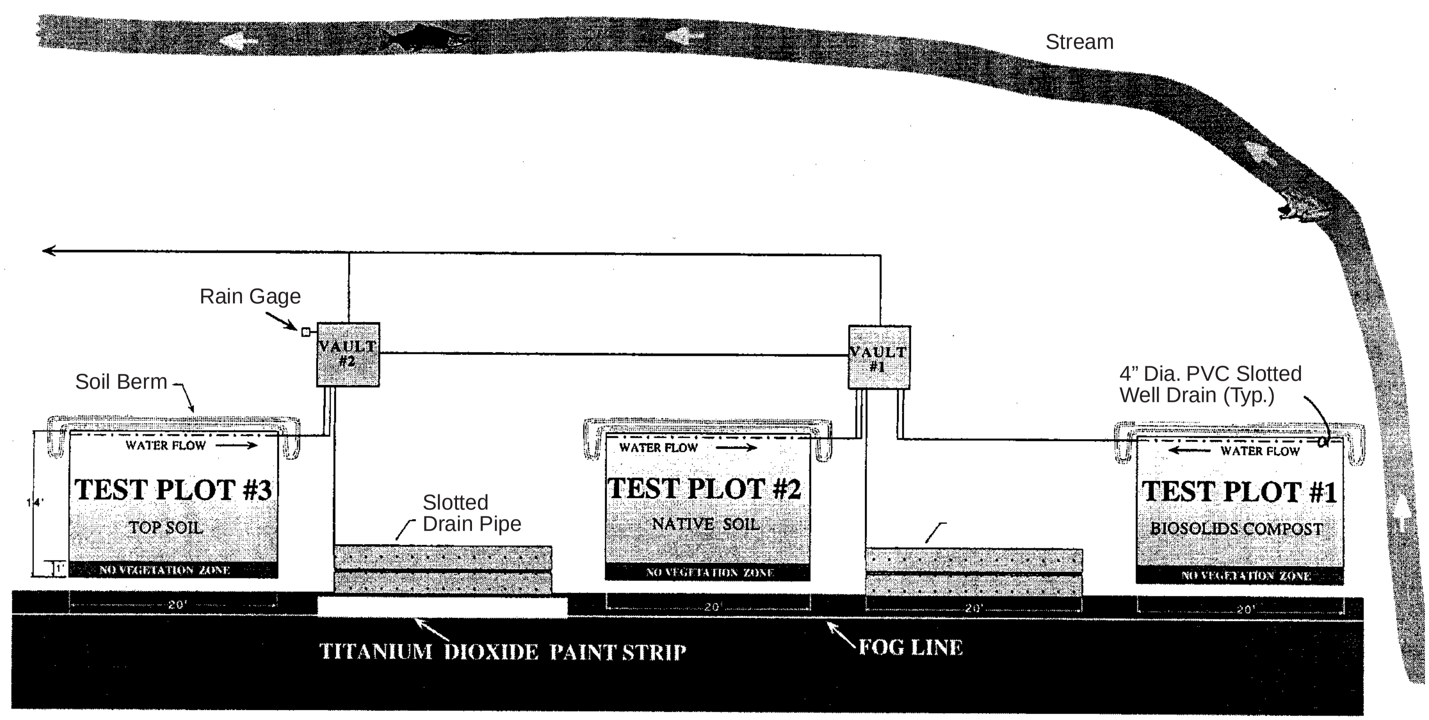

Figure 1. Filter strip BMP plan view site layout.

flow. The vinyl tubing can also be pinched to further reduce the flow.

Ecology Embankment

Research Objective

The research objective is to gather the needed data to see if the ecology embankment can be accepted as a standard BMP in our HRM. The performance of the ecology embankment will be compared to that of the bioswale.

Design

The ecology embankment design was developed as part of a highway improvement project in King County. The project had limited space to install a standard BMP due to wetlands, streams, and riparian buffer zones. The ecology embankment is a modification of the bioswale. The ecology embankments will provide water quality treatment of highway stormwater runoff using the space available in the side slopes of the highway prism to filter out solids suspended in highway stormwater runoff.

Figure 2 shows a cross section of the ecology embankment. The design contains an 8-inch PVC underdrain pipe in a 2-foot-wide trench bedded with gravel at its base. The underdrain pipe and trench allows conveyance of treated runoff.

Above the pipe trench, the embankment contains a minimum 1-foot layer of a mixture of soil and soil amendments, the ecology mix. The ecology mix layer is overlain by a porous geotextile mat. The mat is crush-resistant, pliable, resilient, water-permeable, and highly resistant to chemicals and decomposition. The exposed surface of the embankment is seeded, fertilized, and mulched twice.

A slot drain collects control samples for untreated runoff water quality and runoff volumes. A sampling station vault houses monitoring equipment including 0.4 HS flumes, nutating disc meters, deep-cycle marine batteries, and other equipment.

Difficulties

Accurately recording the discharges through the system may be difficult. We anticipate that the monitoring techniques we ultimately selected for the filter strip research site will work here as well.

The maintenance office was very concerned with the ecology mix and drain pipe associated with this BMP. First, maintenance states that the ecology mix does not have the structural integrity to support vehicle loads. They fear that the travelling public may drive off the road and get stuck in the embankment. Secondly, because the drain pipe requires occasional flushing, the maintenance office felt

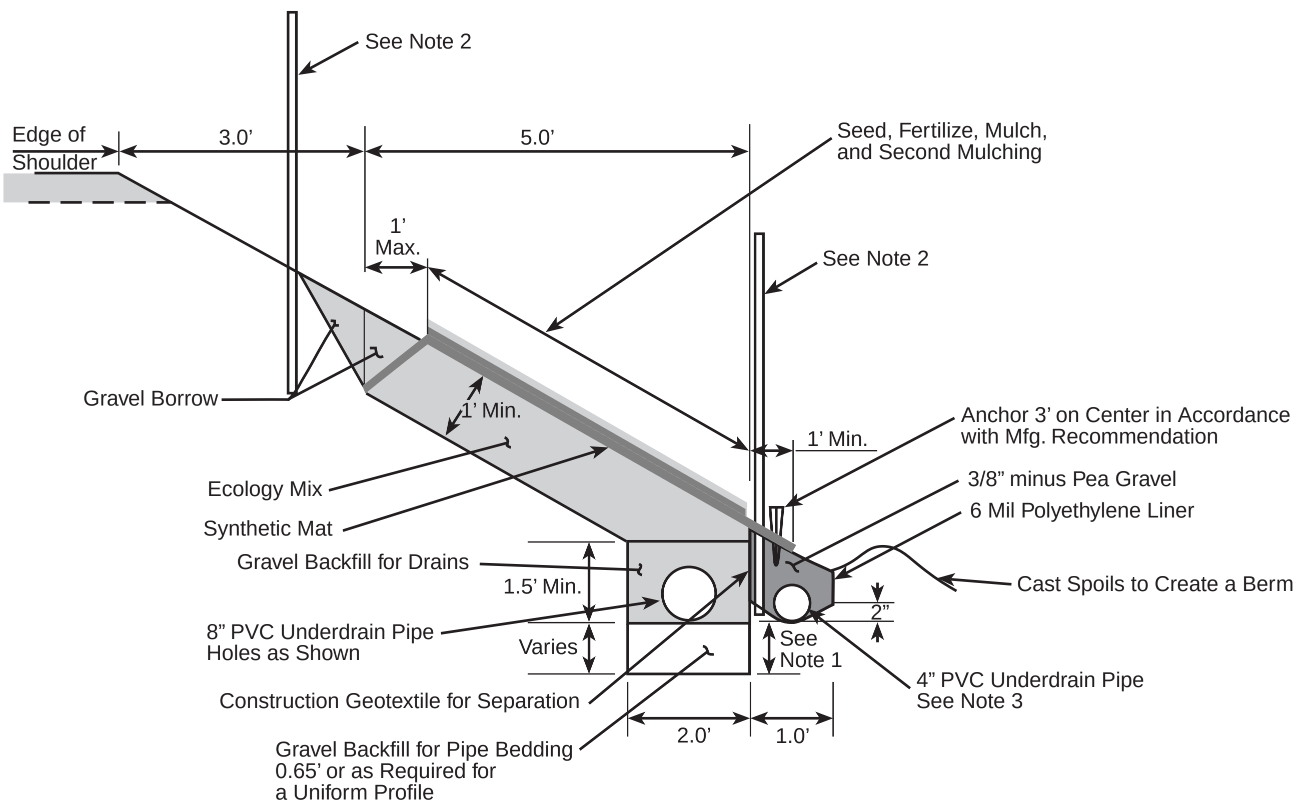

Figure 2. Modified ecology embankment cross section A-A.

that the ecology mix wouldnt support their heavy equipment. The design was modified to allow for flushing of the drain pipe from the edge of pavement. Clean outs will be constructed on the roadway shoulder at a considerably increased cost.

Swirl Concentrator Systems

Research Objective

The Stormceptor™ is a commercially available vault system that utilizes swirl concentrator technology. The primary objective of monitoring the Stormceptor™ is to verify pollutant removal rates independent of manufacturer claims. The manufacturer reports solids removal rates at greater than 85% for low-flow events, with significantly less removal capacity at higher-flow events. Since the manufacturer emphasizes oil and grease removal as one of its main features, grab samples will be collected to provide better estimates of floatable hydrocarbon removal. The second objective is to collect maintenance requirements data.

Design

The Stormceptor™ was selected as part of a highway improvement project in King County. Since the project had limited space to install a standard BMP due to buildings and Metro bus stops, the Stormceptor™ units are installed beneath the pavement in lieu of a catch basin or manhole.

Figure 3 shows the Stormceptor™. It is a dual-level vault designed for ultra-urban settings to enhance the removal of sediments and oil. The Stormceptor™ is divided into a lower storage/separation chamber and upper bypass chamber.

Normal flows are diverted into the lower treatment chamber where oil and other light non-aqueous phase liquids rise. They then become trapped and suspended solids settle to the bottom of the chamber by gravity and centrifugal forces. During high-flow conditions, the bypass chamber conveys water to the downstream storm sewer directly circumventing the lower chamber. This prevents the resuspension and scour of settled pollutants.

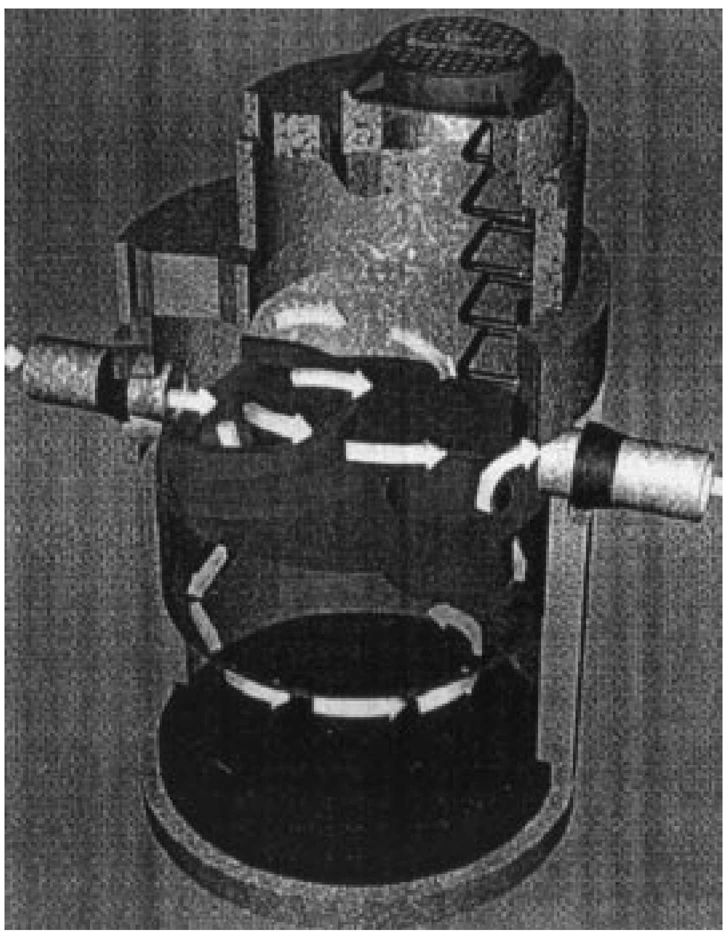

Figure 3. Stormceptor™.

Difficulties

Safety and traffic were major concerns. Placement of the Stormceptor™ vaults along an urban, unlimited access highway, coupled with a dedicated High Occupancy Vehicle (HOV) lanes with Metro bus stations made selection and placement of monitoring equipment difficult. In addition, change orders during the construction phase forced us to step back and re-evaluate our sampling plan. The change orders made it impracticable to use automatic sampling equipment. It was decided that collection of time-composted grab samples was the only option. Grab samples will be collected at the catch basin preceding the BMP and at the outfall to an urban creek.

Enhanced Wet Detention Ponds

Research Objective

WSDOT would like our existing wet ponds to work better. In areas, where native soils have a high clay content, stormwater runoff from construction sites remains turbid even after being detained and passed through a wet pond. The discharges often exceed water quality standards for turbidity and suspended solids. WSDOT is investigating the use of coagulants to improve turbidity removal.

A group of long-chain polymers called polyacrylamides (PAM) were selected to test. Only the anionic form of PAM will be tested. Nonionic and cationic forms of PAM will not be used in WSDOT's experimental BMP because of toxicity considerations. Two PAM products which will be tested in WSDOT's innovative coagulation/flocculation BMP - Cytek Industry's Magnifloc™ 866 A and Magnifloc™ 905N flocculants.

WSDOT plans to test PAM at a detention pond in southern King County. This area has predominately clay loam glacial outwash soils. These soils have a history of problems with mass wasting, erosion control, and water quality because of high levels of turbidity. Slope stability problems preclude construction of additional BMPs. The site receives runoff from approximately 15 acres, 4 of which are currently paved. Monitoring of grab samples of pond effluent registered turbidity readings which, on occasion, have exceeded 200 NTUs.

PAM will be tested at a second pond along SR 5 - Leverich Park near Vancouver, Washington. The detention pond which receives SR 5 runoff was constructed in 1978. During large precipitation events, high levels of turbidity have been observed in the Leverich Park detention pond because of influent highway runoff and resuspension of sediments residing in the pond. PAM can enhance the effectiveness of this detention pond by flocculating suspended sediments and preventing resuspension of sediments that may get discharged to Burnt Bridge Creek.

Design

No special construction provisions are needed for using PAM to enhance sediment removal in stormwater detention ponds. Standard construction and design practices for stormwater detention ponds are adequate.

PAM delivery system will be a "tea bag" device. This can hold granular PAM and be anchored within the influent pipe or channel. During precipitation events, stormwater is expected to infiltrate through the granular PAM tea bag. The PAM mixed with the sediment-laden stormwater is expected to flow into the detention pond, where velocities would be reduced and the flocculation would result.

Preliminary Results

Preliminary results are very promising. Jar tests using sediment laden construction site runoff demonstrate greater than 95% turbidity removal in 30 minutes with 2ppm (parts per million) PAM dosage. The water turned clear, looking nearly like drinking water and the sediment was captured in fluffy, quick settling flocs. The jar tests also demonstrate that the flocs form at as little as 0.8 ppm PAM dosage. Aluminum chlorohydrate is an efficient coagulant and acts as a bridging agent between solids and PAM. Jar tests demonstrate that a one-to-one ratio of aluminum chlorohydrate and PAM further improves the settling process.

Difficulties

WSDOT has been unable to initiate full-scale field tests using PAM. The Department of Ecology is very concerned about the addition of chemicals to the waters of the state. Standard testing protocols are not available and have delayed the testing of this potentially very effective product. Specifically, short-term and long-term aquatic toxicity testing are required.

Ship Canal BMP Research Facility

Research Objective

The objective is to build a full-scale ultra urban highway runoff research facility. The facility will be the testing grounds for new stormwater BMPs designed for limited space situations. Our goal is to have sufficient performance data to be able to select and install BMPs at the lowest possible costs that comply with water quality standards.

Design

WSDOTs most ambitious project is the Ship Canal Stormwater BMP Facility, located in Seattle. This research facility will simultaneously evaluate up to six experimental BMPs treating stormwater runoff from WSDOTs busiest freeway. The use of controls will minimize bias and improve objective comparative evaluations of BMP performance and maintenance requirements. Construction is currently scheduled for the Summer of 1998.

Figure 4 is a schematic of the Ship Canal Research facility. The Research facility will contain four test bays. Space is allowed to add two additional test bays. Commercially available BMPs or custom-designed BMPs can be evaluated at the site.

Difficulties

A local community action group was concerned about polluted discharges from the facility, in the event that one

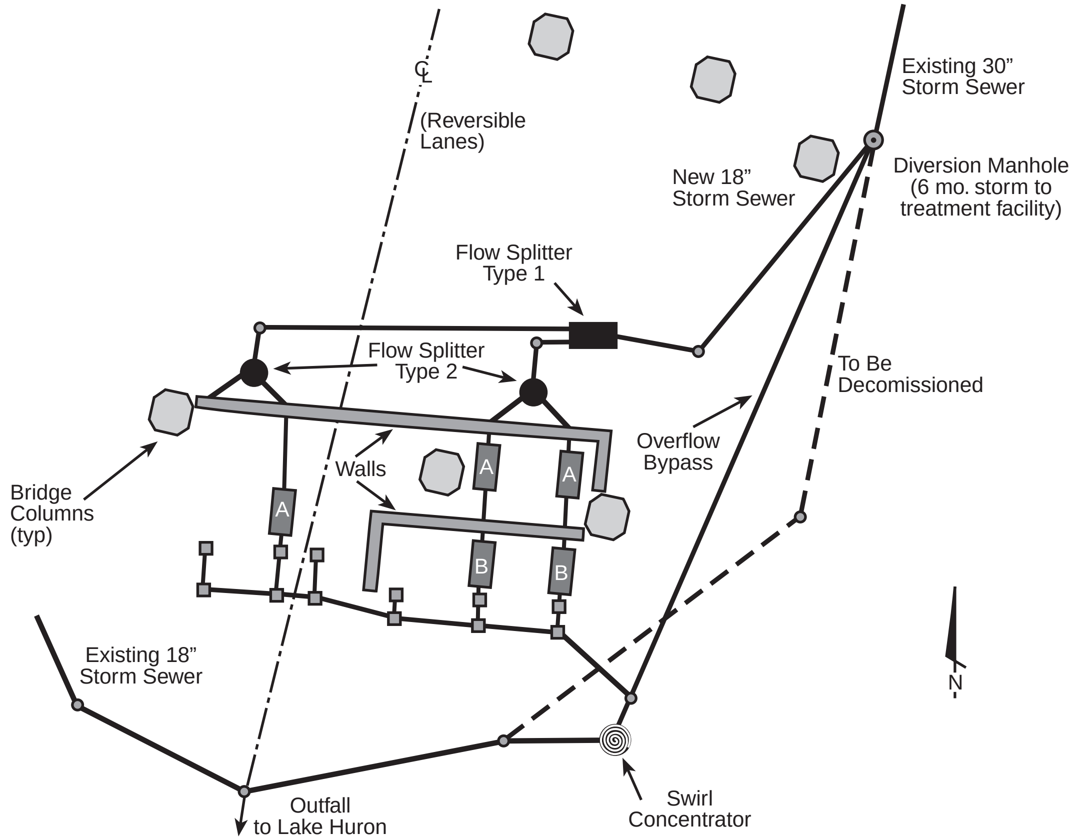

Figure 4. Schematic of ship canal.

of the units failed or had poor performance. Therefore, the design calls for a swirl concentrator-type BMP as a polishing step before discharge into Lake Union.

Because the facility will be built in an urban location, the designer had to work around many issues. Water, cable, and fiber optic lines will need to be relocated. The facility also had to work around the bridge columns. Walls will be constructed because of the large changes in elevation.

The design was first completed in November 1997. The bids were 42% higher than anticipated. Sufficient funds were not available to construct the facility. A second, scaled-back design will be completed during the month of February 1998. We plan to go out to bid during the month of March.

Challenges

There are many challenges when conducting innovative BMP performance monitoring. Finding good research sites takes time and requires thorough research. Major recommendations are:

- Select a safe site for staff and for the traveling public. Give consideration to highway traffic patterns and access. Can sampling staff exit and enter the highway SAFELY?
- Know the hydraulics of the site. In the field there is no such thing as sheet flow. Dips, gouges, bumps and irregularities direct and redirect water into or around the test site. Flow patterns during various storms should be factored. Sites that include drainage from off-site contributors should be eliminated to avoid having to sample all discharges into the site.
- Minimize or eliminate confined spaces from the design. Confined space regulations limit the vertical depth of our sampling vaults to a maximum of four feet; however, the vaults should be deeper to allow for the vertical distance needed for water quality monitoring. Our most recent vault designs allow for both by utilizing a false floor that the sampling staff can safely stand on. Sections of the floor can be removed as needed.
- Minimize travel time. WSDOT tries to locate research facilities within 15 to 20 minutes of the office and within an hour of an environmental laboratory. The longer the commute, the more difficult it is to collect or deliver samples and to pick up spare parts and to make the repairs necessary to keep the facility operational.
- Supervise the construction: as drawn does not mean as built. Review the plans with the project engineer. Then check and confirm the construction as shown in

the plans. Stay in touch and make sure that all change orders are approved by the research staff.

- Allow time to listen and understand resource agency concerns. Balance the need for more effective BMPs against the need for complete environmental understanding and the fate and function of a BMP. If chemicals are added to the water, include short- and long-term toxicity testing and hazardous waste testing of sludges as an element of the testing protocols.

- Innovation means change. Change threatens many people and upsets traditional organizational roles and responsibilities. The next challenging step is to incorporate the research results into how highways are designed and to have the regulating agencies accept designs.

Conclusions

The Washington State Department of Transportation has earned a reputation as an innovative developer of large public works projects. Constructing and maintaining transportation facilities will always be the primary mission of WSDOT.

However, the agency accepts responsibility for the potential environmental and social impacts of our facilities. A major responsibility is to protect our state's water quality and to preserve our environmental values. WSDOT has adopted the watershed-need philosophy as the best way to provide cost-effective water quality treatment.

The Innovative BMP Research program will help provide clear selection criteria and design parameters for stormwater BMPs. This, in turn, will provide the best BMP for each project or outfall site. As the years go by, WSDOT anticipates a diminishing impact to watersheds from its transportation facilities.

StormTreat™ Technology for Stormwater Treatment

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Stormwater treatment standards throughout the nation have focused on removal of suspended solids, trusting that other contaminants will be removed as well. Massachusetts, for example, requires 80% suspended solids removal. While this is an important first step, there are a wide range of other contaminants such as fecal coliforms, nutrients, metals and hydrocarbons that may not be treated by technologies focusing solely on suspended solids removal.

The StormTreat™ System (STS) was developed in 1994 in response to the need to provide enhanced treatment of stormwater, beyond suspended solids removal. The technology is designed to capture the "first flush" of runoff, and provide treatment in a 9.5-foot diameter tank through sedimentation, filtration and constructed wetlands uptake. Two years of independent testing results indicate removal rates of 97% for fecal coliform bacteria, 90% for phosphorus, 77% for dissolved nitrogen and 99% for total suspended solids.

StormTreat™ is the first stormwater technology to be verified by the Massachusetts Strategic Environmental Partnership (STEP) Program, a state program designed to verify the claims and effectiveness of new technologies. The Massachusetts STEP program is part of a six-state Partnership for Environmental Technology, including Illinois, California, Pennsylvania, New Jersey and New York.

StormTreat™ has recently developed an optional infiltration feature to treat stormwater from as much as one impervious acre per unit. This is accomplished by infiltrating treated water directly into surrounding and underlying soils. With this option, treatment costs can be reduced to as low as $7,000 per acre treated (including installation).

Introduction

Stormwater runoff from streets, parking lots and adjacent areas is one of the most significant water pollution problems today. Lakes, reservoirs, streams, coastal waters and related wetlands receive "pulses" of oils, metals, bacteria, nutrients and other pollutants during and following each storm event. Where stormwater is infiltrated or injected into groundwater, impacts may occur to subsurface drinking water supplies.

Chronic petroleum hydrocarbon discharges to the marine environment from stormwater runoff far outweigh those from catastrophic oil spills from tanker ships (such as the Exxon Valdez). Researchers associated with the EPA-sponsored Buzzards Bay National Estuary Program have concluded that stormwater-derived bacterial loadings are responsible for the majority of shellfish area closures. Stormwater has also been documented as a major cause of eutrophication of lakes and ponds nationwide.

Non-point sources of pollution such as stormwater typically originate from diffuse areas. Stormwater is generated from streets, parking lots, roof tops, driveways, lawns, agricultural fields and forests (Figure 1). Frequently, stormwater runoff from several of these various "land uses" is combined into a stormwater flow in a drainage ditch or stormwater pipe which ultimately discharges to a receiving water where the impacts are realized. Because of the diffuse nature of sources, stormwater management is best accomplished by a watershed management technique which treats each area within the watershed independently as opposed to the more conventional "big pipe" solution where a large detention/treatment system is constructed at the bottom of a watershed attempting to catch and treat all of the stormwater generated within the watershed.

There is a direct relationship between the traffic volume on a road and the concentrations of metals found in the stormwater. This suggests that stormwater quality is likely to degrade over time as urbanization continues and land use densities increase. A study conducted by Arnold and Gibbons (1996) has shown a direct relationship between the percentage of impervious cover and the quality of adjacent surface waters. When impervious surfaces cover 30% of the land area, significant water quality impairment is evident.

While there is a wide variety of compounds present in stormwater, the majority of treatment approaches focus

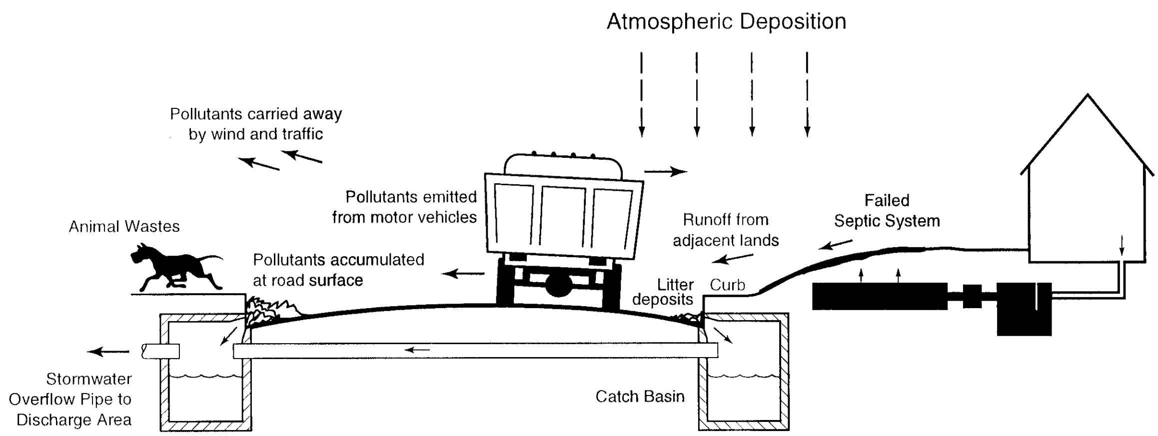

Figure 1. Stormwater Pollutant Pathways.

on removing suspended solids. The premise is that if suspended solids are removed, a wide range of other pollutants associated with the solids are removed as well. Removal of suspended solids is used as a performance standard in numerous stormwater regulations. The most recent example may be the State of Massachusetts which now requires 80% suspended solids removal for treatment systems approved within 100 feet of inland or coastal wetlands (MA DEP, 1997).

There are two problems with this thinking. First, the majority of the suspended solid particles (Table 1) are very small, with 78% of them less than 44 µm in diameter (Rexnord, 1984). This presents significant problems with respect to best management practices (BMPs), which rely wholly upon physical settling, or separation, of solids. The settling rates associated with silt and clay-sized particles are on the order of several hours to days per foot of settling. This has significant implications with regard to the effectiveness of detention basins and other treatment approaches in meeting performance standards.

Second, a significant percentage of most pollutants is associated with the finer particles (Table 2). For example, approximately 56% of phosphates in stormwater is associated with particles smaller than 43 µm. If the smaller particle sizes are not removed, the expected treatment of other constituents is not obtained.

Table 1. Wet Sieve Analysis of Highway Runoff Composite Samples

	Percent of Suspended Solids				
Particle Size (µm)	Sacramento Hwy. 50	Harrisburg I-81	Milwaukee I-94	Effland I-85	Mean
> 250	1.54	6.10	14.56	3.58	6.45
88-250	9.07	6.70	7.00	1.30	6.02
44-88	10.70	11.70	5.84	8.06	9.08
< 44	78.69	75.50	72.60	87.06	78.45

Source: Rexnord, Inc., 1984

Generally speaking, a "first flush" effect is observed with stormwater quality. The highest pollutant concentrations are typically observed at the beginning of a storm event. This is because of the residues which are available on paved surfaces at the beginning of a rain event. As this first flush is washed from the paved surface, pollutant concentrations typically decline throughout the remainder to the storm event. The "first flush" principle has been commonly observed for total suspended solids. Up to 90% of the total suspended solids (TSS) are contained within the first 0.5 inches of runoff (EPA, 1974).

There are exceptions to the first flush principle. For example, a long light rain followed by a strong downpour may exhibit its highest concentrations of pollutants toward the end of a storm event. However, when one averages all rainstorms, the majority of annual pollutant loading occurs during the first flush. Another exception is a large watershed which has a long "time of concentration" (the time required for water to flow from the uppermost part of the watershed to the final point of discharge). In these cases, samples taken at the discharge point may integrate the first flush from the bottom of the watershed but miss the first pollutant loadings from the upper part of the watershed.

The StormTreat™ System

The StormTreat™ System was designed in 1994 in an effort to treat stormwater in a way that would effectively remove a broad range of pollutants in addition to suspended solids. It saves space by reducing the need for unsightly detention basins. It captures and treats the first flush of runoff which contains 90% of pollutants. An optional infiltration feature provides for the treatment of larger quantities of stormwater, beyond the first flush, as described later in this paper.

The system consists of a series of six sedimentation chambers and a constructed wetland which are contained

Table 2. Percent of Street Pollutants in Various Particle-Size Ranges

Pollutant	Particle Size (μm) >2000	840-2000	240-840	104-240	43-104	<43
Total solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile solids	11.0	17.4	12.0	16.1	17.9	25.6
COD	2.4	4.5	13.0	12.4	45.0	22.7
BOD_5	7.4	21.1	15.7	15.2	17.3	24.3
Phosphates	0	0.9	6.9	6.4	29.6	56.2
All toxic metals	16.3	17.5	14.9	23.5	—	27.5
TKN	9.9	11.6	20.0	20.2	19.6	18.7
All pesticides		27.0			73.0	
PCBs		66.0			34.0	

Source: EPA, 1983

within a modular 9.5-foot diameter tank (Table 3). It is constructed of recycled polyethylene which connects directly to existing drainage structures.

Influent is piped into the sedimentation chambers where larger-diameter solids are removed (Figure 2). The internal sedimentation chambers contain a series of skimmers which selectively decant the upper portions of the stormwater in the sedimentation basins, leaving behind the more turbid lower waters. The skimmers significantly increase the separation of solids compared with conventional settling/detention basins. An inverted elbow trap serves to collect floatables such as oils within one chamber of the inner tank. After moving through the internal chambers, the partially treated stormwater passes into the surrounding constructed wetland through a series of slotted PVC pipes.

The wetland is comprised of a gravel substrate planted with bulrushes and other wetland plants. Unlike most wetlands constructed for stormwater treatment, StormTreat™ conveys stormwater into the subsurface of the wetland and through the root zone, where greater pollutant attenuation occurs through such processes as filtration, adsorption, and biochemical reactions.

Precipitation of metals and phosphorus occurs within the wetland substrate while biochemical reactions, including microbial decomposition, provide treatment of the stormwater prior to discharge through the outlet valve. An outlet control valve provides up to a 5-day holding time

Table 3. StormTreat™ Specifications

StormTreat™ Specifications	
Diameter	9.5 ft
Height	4 ft
Storage Capacity	1390 gal
Inflow Pipe Diameter	4 in
Outflow Pipe Diameter	2 in
Average Detention Time	5 days
Average Discharge Rate	0.25 gal/min
Tanks Required per Acre of Impervious Surface	2-5 Tanks*

* The number of tanks depends upon the level of treatment required, the in-line detention capacity and the use of the optional infiltration feature.

within the system. The valve can be closed to contain a hazardous waste spill.

The size and modular configuration of StormTreat™' makes it adaptable to a wide range of site constraints and watershed sizes. It can be installed in any type of soil as the discharge rate is very low (0.25 gal/min) and the gravel filter/wetland substrate is contained within the system. As the flow through the system is gravity dependent, the system requires an elevation change from the pavement surface to a discharge point of at least 4 feet.

StormTreat™ has been installed in a variety of applications, including commercial parking lots, industrial sites, town landings and marinas, transportation facilities and residential subdivisions. It is an appropriate treatment technology for both coastal and inland areas, and can be used throughout the country with only minor system modifications to fit local conditions.

To date, 315 analyses have been conducted on 33 samples which have been collected over eight independent storm events during both winter and summer conditions in New England. Influent stormwater samples were taken at the entry point to the StormTreat™ tanks at the catch basin. Effluent samples were taken during the 5 days following the storm event. The quality of the sampled effluent was then compared with influent and removal rates were computed. Test results are summarized in Table 4.

StormTreat™ requires minimal maintenance. Annual inspection is recommended to ensure that the system is operating effectively. At that time the manhole is opened and the burlap grit screening bag covering the influent line should be removed and replaced; filters should be removed, cleaned, and reinstalled. Sediment should be removed from the system via suction pump once every 3-5 years, depending on local soil characteristics and catch basin maintenance practices.

State Verification

StormTreat™ is the first and only stormwater treatment technology to be verified by the Massachusetts STEP Program. The Strategic Environmental Partnership (STEP) Program is a service provided by the Commonwealth of Massachusetts to help develop new environmental technologies and to verify their effectiveness. Both business management and technological expertise is provided through the University of Massachusetts. An excerpt from the executive summary of this assessment reads as follows:

"It is the conclusion of this assessment that the (StormTreat™) system, when sized according to recommended criteria, with proper operation and maintenance, can provide levels of treatment required under Standards 4 and 6, as specified by the Massachusetts DEP Stormwater Management Handbook. Under special circumstances, the system may provide as much as 98% removal of TSS when sized according to design criteria. The system, when configured for recharge can meet Stan-

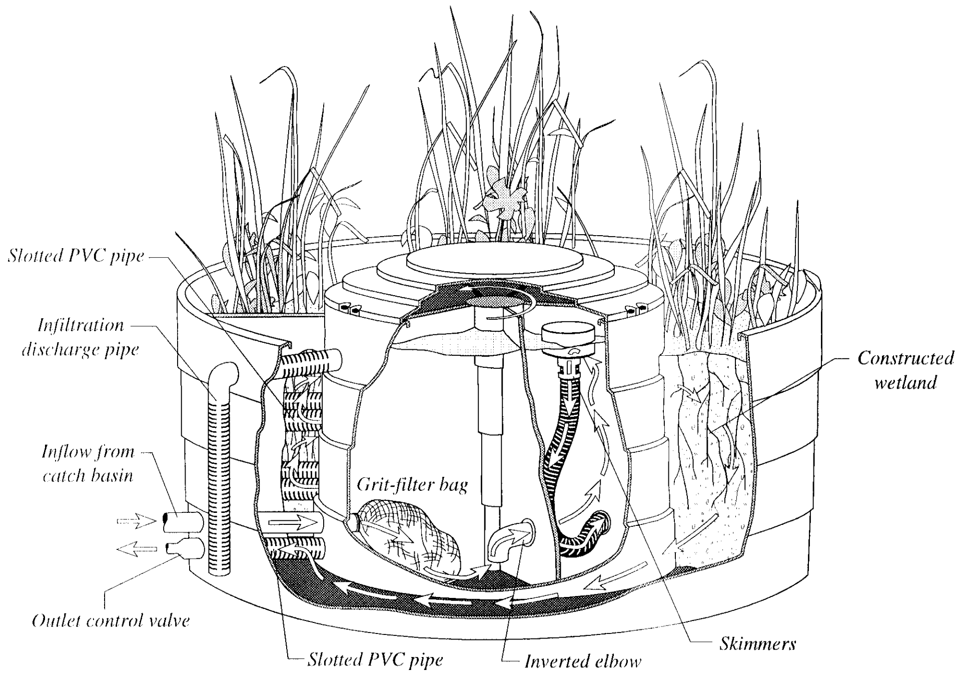

Figure 2. Schematic cross section of StormTreat™ system.

Table 4. Water Quality Sampling Results, Kingston, MA

Pollutant	Average Stormwater Influent	Average Treated Discharge	Percentage Removed (%)
Fecal coliform (no./100 ml)	690	20	97
Total suspended solids (mg/l)	93	1.3	99
Chemical oxygen demand (mg/l)	95	17	82
Total dissolved N (mg/l)	3569	520	77
Total Petroleum Hydrocarbons (mg/l)	3.4	0.34	90
Lead (mg/l)	6.5	1.5	77
Chromium (mg/l)	60	1	98
Phosphorus (mg/l)	300	26.5	90
Zinc (mg/l)	590	58	90

Note: Samples were collected by the Jones River Watershed Association in accordance with EPA sampling protocol, and analyzed at state-certified laboratories (Schueler, T. 1995).

dard 3 and is also likely to meet Standard 5, for land uses with higher potential pollutant loads, when sized according to design criteria."

The Massachusetts STEP is a member of the Six State Partnership for Environmental Technology which includes California, Pennsylvania, Illinois, New Jersey, and New York. Reciprocal certifications in these states may be available.

Infiltration of Treated Stormwater

An optional infiltration feature enables the StormTreat™ System to process as much as one acre of impervious surface area per unit. This is accomplished by directing *treated* stormwater into the surrounding and underlying soils (Figure 3). There are several advantages to this approach. First is the replenishment of groundwater. Under natural (undeveloped conditions) a certain percentage of precipitation infiltrates through the soils and recharges underlying groundwater (this may be as high as 50% of the annual precipitation resulting in groundwater recharge in the Northeast US). Commonly, the development of land results in an increase of impervious surfaces reducing the recharge rate (in some cases to zero). Less recharge means less water supply availability, declining water tables and less baseflow (discharge) to nearby streams and wetlands.

A second advantage of this new feature is significantly-increased treatment and lower costs to customers (as low as $7,000/acre installed). By allowing treated stormwater to infiltrate into the surrounding soils, additional treatment capacity is achieved. This is accomplished first by infiltrat-

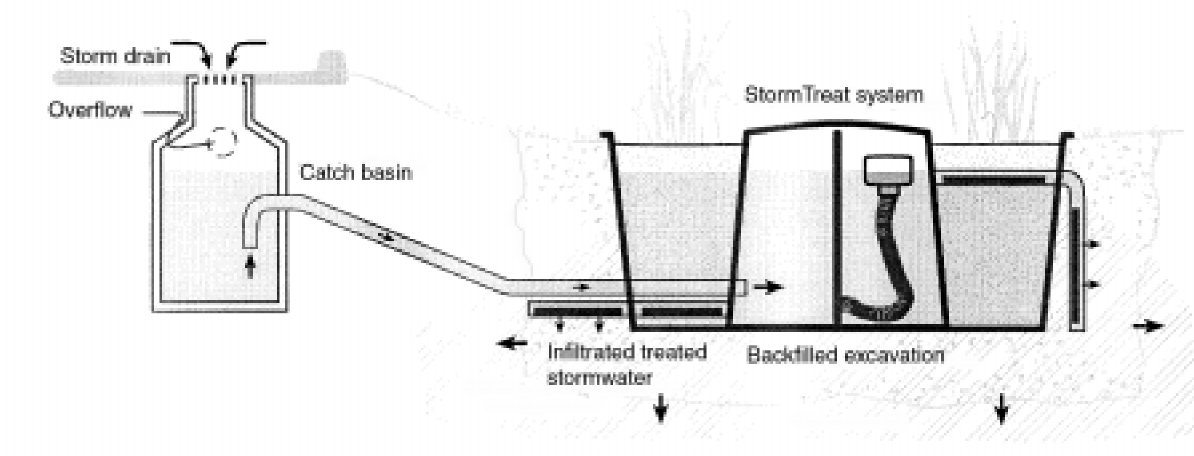

Figure 3. Schematic cross section showing new infiltration feature.

ing into the surrounding backfill materials (specified as 3/4-inch stone). This stone is highly permeable and serves to transmit the treated water downward and laterally until it encounters the parent soils. During peak flow periods, the infiltration rate may exceed the permeability of the parent soils and the stone backfill area serves as a temporary storage reservoir.

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Evaluation of Stormceptor® and Multi-Chamber Treatment Train as Urban Retrofit Strategies

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Introduction

The installation of water quality best management practices (BMPs) in developed urban areas is problematic. A landscape comprised of buildings and pavement presents little opportunity for placement of new BMPs. To overcome this obstacle of limited space, a new set of retrofit BMP technologies are emerging which utilize space underground, thereby avoiding disruption to current aboveground land uses. This paper evaluates the water quality benefits of two retrofit BMPs, the Stormceptor and the Multi-Chambered Treatment Train (MCTT). The installation of these devices and the subsequent evaluations were cooperative efforts involving the US Environmental Protection Agency, US Geological Survey, cities of Milwaukee and Madison, (Wisconsin), StormceptorÆ Corp., University of Alabama-Birmingham, and Wisconsin Department of Natural Resources.

Study Design

Description of Test BMPs

The Stormceptor consists of a treatment tank and bypass chamber (Figure 1). Water initially enters the bypass chamber from an upstream stormsewer. During periods when the flow doesn't exceed the unit's capacity, water is diverted down a drop pipe, where water is discharged tangentially along the chamber's wall. Suspended sediment falls to the bottom of the tank where after a period of accumulation, it is pumped out and landfilled. Water exits the treatment chamber at the opposite end through a similar drop pipe and drains to the downstream stormsewer. Hydrocarbons and other lighter-than-water materials are trapped above the treatment tank's drop pipes. During periods of surcharge, the portion of the stormwater in excess of the treatment rate flows directly over the weir in the bypass chamber and receives no treatment. The unit chosen for this project was the STC 6000. Its capacity is 6150 gallons and it is designed for a treatment flow capacity of 800 gal/min. The treatment tank is 10 ft in diameter and 10 ft deep.

The MCTT consists of three components, an inlet area, a settling chamber, and a filter bed (Figure 2). The largest grit material accumulates in the bottom of the 4 ft inlet basin. In addition, water passes over a mesh bag of column packing balls which enhance aeration and loss of highly volatile components. The second chamber has inclined tube settlers which further enhance the settling process. This chamber also contains sorbent pads which remove floatable hydrocarbons. Water drains slowly from the second chamber into the filter bed chamber via a 0.35-inch orifice. This final chamber contains a mixed media of sand/ peat/ activated carbon supported by filter fabric and is designed to remove fine particles along with some dissolved constituents via sorption and ion exchange. The second and third chambers are constructed from a partitioned concrete box (10 ft wide x 19 ft long x 5 ft high). The capacity of the settling chamber is 750 ft^3 although the height of the orifice results in a "dead storage" capacity of 375 ft^3, leaving the actual storm volume capacity at 375 ft^3. Once this capacity is reached, the excess water is bypassed.

Site Descriptions

Both study sites are public works maintenance yards used for fueling, storage and maintenance of city vehicles, most of which are heavy trucks. In addition, open storage of sand, salt and yard wastes can be found at times. The Stormceptor was installed at the Badger Rd. public works garage in Madison, Wisconsin. One stormsewer inlet collects the runoff water from the entire facility (4.3 acres) and the Stormceptor was retrofitted in the existing stormsewer approximately 300 ft from the inlet. The MCTT was constructed at the Ruby St. garage in Milwaukee, Wisconsin. The unit receives water from only a portion (0.2 acres) of the paved area.

Sampling Design

Similar sampling strategies were employed for the evaluation of both these devices. The evaluation consisted basically of collecting flow-integrated samples at the influent and effluent for each BMP. In addition, the Stormceptor's

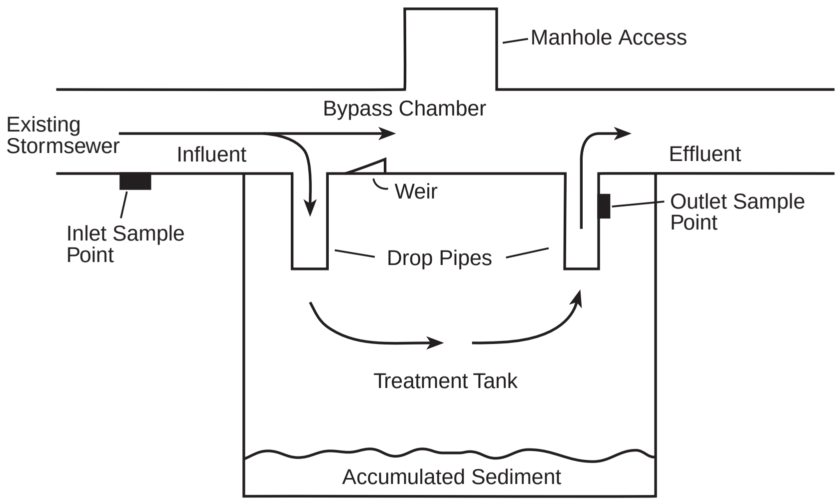

Figure 1. Cross section of Stormceptor® device showing placement of sampling points.

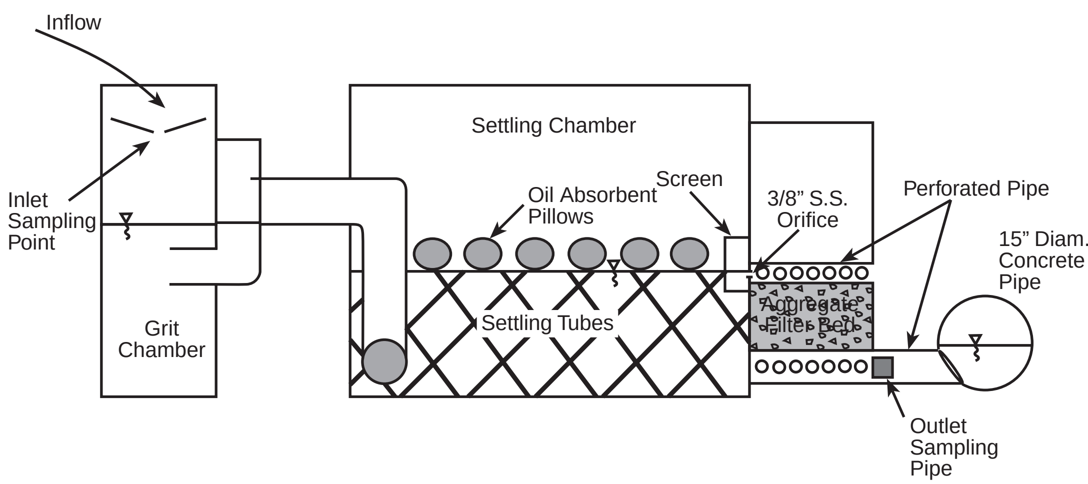

Figure 2. Cross section of MCTT device showing placement of sampling points.

bypass water was also collected. The locations of sampling ports are shown in Figures 1 and 2.

Sampling equipment and monitoring instrumentation were housed in small onsite buildings. In addition, tipping bucket rain gages were placed on nearby rooftops. Dataloggers served as the site controller, with a modem and telephone for external communications. At both sites, flow was measured either directly, with a doppler or electromagnetic flow meter, or indirectly, with a pressure transducer/stage height measurement. The datalogger was programmed to initiate rainfall, stage, and velocity measurements on a variable time scale. Measurements were taken more frequently during runoff periods and less frequently during dry periods. The data were recorded using internal memory of the datalogger and a backup storage module, and transferred every 24 hours via modem to the USGS computer in Madison.

Both sites had two refrigerated samplers equipped with peristaltic pumps and Teflon-lined sample tubing to collect water quality samples. The automatic samplers were triggered by the datalogger to initiate collection of storm samples. One composite sample each was collected at the inlet and the outlet for each storm. Each sample contained between 5 and 40-stormflow volume-weighted subsamples, which resulted in event-mean concentrations.

Fifteen consecutive storms were monitored at the MCTT site from April 29, 1996 through September 8, 1996. A total of 68 constituents were measured in the samples taken at the MCTT device. At the Stormceptor site, 45 storms were monitored from the period of August 6, 1996 to May 1, 1997. Samples from 15 of the 45 storms were analyzed for 37 constituents included a variety of solids, nutrient, metals and polycyclic aromatic hydrocarbons (PAHs). The remaining 30 storm samples were analyzed only for total suspended solids (TSS), total dissolved solids (TDS) and total phosphorus (TP). In both studies, loads and removal efficiencies were calculated (load=storm volume x event-mean concentration). Two types of removal efficiencies were calculated: tank efficiencies based on reduction of load of stormwater passing through the tank, and overall removal efficiency, which also accounts for load which is bypassed. In addition, particle-size characterization was performed on 15 samples at each site. Only a few constituents are presented here to highlight the studies' findings. Complete results can be obtained from the USGS Water Resource Division in Madison, Wisconsin.

Results

Stormceptor

Precipitation for the 45 monitored storms ranged from 0.02 to 1.31 inches. This rainfall produced runoff amounts ranging from 120 ft^3 to 30,000 ft^3. Though for 24% (11 out of 45 storms) water bypassed the unit, the total water volume that bypassed equaled only 9%. Stormwater was observed bypassing the treatment tank at flows greater than 500 gal/min, which is less than the manufacturer's specification of 800 gal/min. This difference may have been caused by the exit sewer pipe being slightly higher in elevation than specifications called for, causing a back pressure through the unit and resulting in the unit bypassing more often.

The influent total suspended solids (TSS) concentrations found are comparable to parking lot and street runoff concentrations observed elsewhere in Wisconsin (Bannerman et al., 1993) and other locations (Ellis, 1986). The influent TSS event-mean concentrations for the 45 storms ranged from 43 to 1236 mg/l with a median value of 251 mg/l. In general, the highest influent TSS concentrations were observed in the winter months, presumably reflecting the high activity of sand/salt trucks in the yard area. The influent TSS load ranged from 0.45 to 224 kg. and the cumulative influent load for the 45 measured storms was 1670 kg. An estimated 91% of this load entered the treatment tank; the remaining 9% was bypassed.

The TSS concentrations of the water exiting the treatment tank had a median concentration of 151 mg/l and ranged from 45 to 615 mg/l, approximately half the range of the influent concentrations. The total load exiting the treatment tank (1044 kg.) resulted in an overall removal efficiency for the treatment tank of 26%. The effluent TSS load totaled 1294 kg. (from 4.3 acres) for the 45 storms, indicating an overall reduction efficiency (treatment tank + bypass) of 22%. Because of the hydraulic residence time of the treatment tank, effluent water can be a mixture of influent waters from a number of previous storms. Therefore, caution must be used in interpreting individual storm efficiency results. In general, the monitored storms had sufficient runoff water to replace the majority of water in the treatment tank. Eighty-four percent of the storms exceeded one tank volume, 62% exceeded two tank volumes. Figure 3 illustrates the relationship between the individual effluent load and overall efficiency. There appears to be considerable variation in efficiency for the smaller storms and, in general, as the storm loads become larger, the efficiency decreases.

Total Dissolved Solids (TDS) concentrations were also quite variable, ranging more than two orders of magnitude in both the influent and effluent (median influent and effluent concentrations were 3860 and 4700 mg/l, respectively). Similar to TSS concentrations, the TDS concentrations showed a marked increase during the winter season, presumably due to salt stockpiled onsite and spillage from trucks. The maximum TDS concentration (114,000 mg/l) was on 1/26/96. Negative removal efficiencies were found for both the treatment tank and the overall system (both at -19%). The fact that efficiencies were negative may be due to either measurement errors or possible dissolution of granular salt within the tank. It is interesting to note that

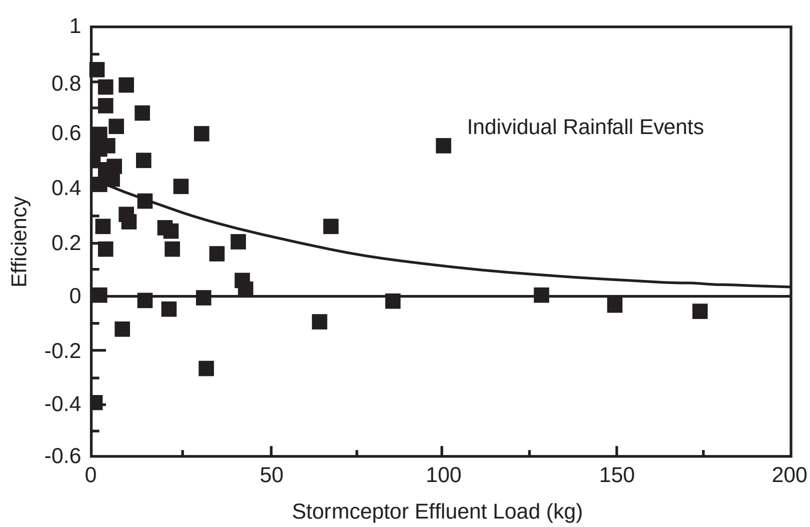

Figure 3. Relationship between individual effluent load and overall efficiency at the Stormcepter® site.

the influent TDS load was more than 20 times the TSS load.

Total phosphorus (TP), the third constituent measured in all 45 monitored events had concentrations ranges from 0.08 to 1.3 mg/l in the influent and 0.06 to 0.86 in the effluent. The tank and overall removal efficiencies (20% and 18%, respectively) were somewhat less than TSS removal rates.

The remaining 34 constituents were measured in 15 storm samples only. In general, the removal efficiencies of the total constituent loads were similar to the TSS removal rates and none had negative efficiencies. Total polycyclic aromatic hydrocarbons exhibited the highest overall removal rate (32%). Of the four metals quantified, zinc had the highest concentrations and loading. The overall reduction efficiency for total zinc was 21%. Removal efficiencies of the dissolved constituents were always less than the total constituents with the exception of dissolved phosphorus, which interestingly was slightly greater than total phosphorus. Five dissolved constituents had negative efficiencies, which may of been a result of load errors, dissolution in the tank and redox processes in the tank's accumulated sediment. The increase in chloride mass further suggests that granular sodium chloride is going into solution after entering the tank. Given that the device is basically designed for particulate solids removal, the negligible removal of dissolved constituents was anticipated.

Particle-size analyses of the 15 influent and effluent samples showed little shift in the size distribution (Figure 4). The small clay-size fraction increased slightly from 3.3 to 3.6%. Silt was the predominant size fraction and increased from 88.9 to 93%; the sand fraction decreased from 7.8 to 3.5%.

At the end of the study period, the oily surface material, water, and bottom sediments were pumped from the treatment tank. Approximately 16 ft^3 of floating oily material was captured at the top of the treatment tank. As the tank was pumped down, the water was subsampled for TSS and TDS. An increasing gradient in TDS concentration was observed from top to bottom. At 7 ft from the top of the tank, the TDS had increased from 51,000 to 138,000 mgl. Greater water density caused by this high salinity could have hindered particulate solids settling. In addition, this sharp increase in density may have resulted in a portion (30-40%) of the tank's volume being resistant to mixing, thereby decreasing the treatment ability of the tank. Using the manufacturer's sizing guidelines, this decreased effective volume would cause a marked decrease in tank efficiency. But inconsistent with this hypothesis is the fact that the first 14 storms (before the saline buildup) exhibited a total removal efficiency of only 5% and the last 14 storms monitored (during the period of high saline conditions) had above average (25%) removal. Therefore, the impact of the salt on the tank's settling ability is unclear at this time.

The depth of sediment accumulated on the bottom was measured and then subsampled and analyzed for dry weight, particle size, metals and PAHs. As a mass balance check on the sediment material removed by the treatment tank, the measured mass of sediment deposited in the tank was compared to the difference in influent and effluent TSS mass. Based on sediment depth and dry weight, the mass was calculated to be 536 kg. This value compares favorably with a TSS load estimate of 473 kg. These similar mass values lend credence to the methodologies used to sample the stormwater flow and concentrations.

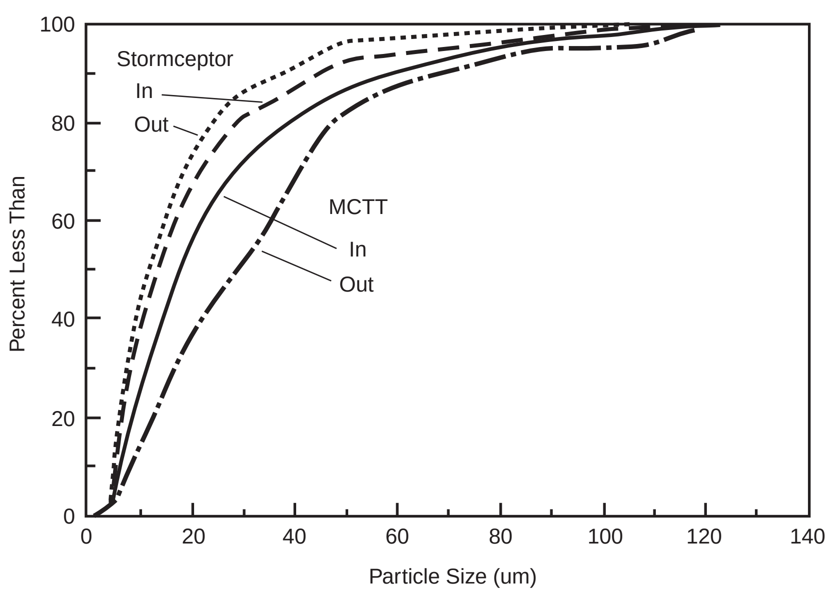

Figure 4. Mean particle-size distributions of influent and effluent TSS for both studies.

The treatment tank was found to be quite selective with respect to removal of the larger-sized particles. The sieving of this material found 80% had a particle size of greater than 250 µm. This finding suggest the influent stormwater may have had a higher concentration of the sand-size fraction than was found in the suspended solids particle size analyses. Larger sand-size material, saltating along the bottom of the stormsewer pipe may have not been accounted for in the TSS loading. This unaccounted material would further explain why the TSS load (473 kg) is somewhat lower than what was measured in the tank. If the tank efficiency was based on the mass collected in the tank (536 kg.) instead of the TSS load difference (473 kg.), the TSS removal efficiency would increase by 28 to 34%.

The Multi-Chambered Treatment Train

Fifteen storms occurring from April 29, 1996 through September 8, 1997 were monitored and sampled. Rainfall amounts for these storms ranged from 0.18 to 1.37 inches. Based on the delineated drainage area (0.2 acres), total rainfall volumes ranged from 107 to 815 ft^3. The actual quantity of water passing through the MCTT ranged from 60 to 319 ft^3 and comprised approximately 60% of the rainfall volume. The other 39% of the rainfall volume may have been lost through cracks in the aged pavement surface or in joint leaks between the catch basin and the main chamber. An overestimation of the drainage area may also account for this difference. A consequence of this loss in stormwater was that the unit never surcharged, even though the design hydraulics would have suggested 10 out of the 15 storms monitored should have surcharged and approximately 22% of the total stormwater should have bypassed. This fact made the calculation of overall efficiency problematic.

Total suspended solids influent concentrations from the MCTT ranged from 79 to 1050 mg/l, with a median concentration of 232 mg/l, values comparable to TSS concentrations found in runoff samples at the Stormceptor site. A majority (8 out of 14) of the effluent TSS were below the detection limit. The highest concentration of TSS observed in the effluent was 18 mg/l. The cumulative influent load of TSS to the unit for the 15 consecutive storms was 18.3 kg. The effluent TSS load was only 0.30 kg, making the unit's removal efficiency greater than or equal to 98%. Examination of concentrations at intermediate points, (Pitt et al. 1997) found the majority of the TSS was removed in the settling chamber.

Though the overall TSS removal efficiency was impossible to directly measure due to the water loss problems discussed above, an overall TSS removal was estimated because it is widely used as a key parameter in BMP evaluations. To calculate an overall TSS removal efficiency, it was assumed that any storm volume in excess of the settling tank's capacity (375 ft^3) would bypass the unit. This method resulted in a calculated overall TSS removal efficiency of 78% for the 15 storms monitored.

Total dissolved solids (TDS) influent samples had a median value of 652 mg/l with a range from 164 to 5930 mg/l. The major source of the dissolved solids was a store of road salt located within the drainage area. This salt resulted in a large load of dissolved solids (sodium chloride) to the unit which was 4.5 times the particulate (suspended solids) portion of the solids load for the period of study. The MCTT removed 13% of the TDS load.

Total phosphorus ranged from 0.10 to 0.44 mg/l with a median value 0.25 mg/l. Effluent concentrations were generally an order of magnitude less (median= 0.03 mg/l). This loss signaled a quite high tank removal efficiency of 88%. Dissolved phosphorus was consistently less than 10% of the total phosphorus in both the influent and effluent samples. Dissolved phosphorus removal efficiency (78%), though somewhat less than total phosphorus removal, was still substantial.

Of the five metals examined, total zinc concentrations were consistently the highest (median = 150 mg/l). The removal efficiency for total zinc was 91%. A very high level of removal was observed for all the metals. Because the majority of the total metal concentrations were in the particulate form, the physical removal of this material may be occurring in all three chambers of the unit, although the bulk of the material (associated with the suspended solids) is most likely being removed in the settling chamber.

The removal efficiency of dissolved zinc was 68%, which was somewhat less removal than total zinc. Actual removal may have been greater because effluent concentrations were generally at detection limits.

Total polycyclic aromatic hydrocarbon concentrations (sum of all 16 species) in the influent samples ranged from 2.9 to 23 mg/l. Total fluoranthene and pyrene consistently had concentrations that were more than double the concentrations of other PAH species with median concentrations of 1.8 and 1.4 mg/l, respectively. The total PAH removal efficiency was 94%. The dissolved PAHs averaged 14% of the total concentrations (dissolved PAH conc./total PAH conc.). The only dissolved PAH species which was consistently reported above detection was phenanthrene (median=0.1 mg/l). Because the majority of the PAHs were found in the particulate fraction, most of the removal probably occurred in the settling chamber, which is collaborated by (Pitt et al. 1997). Table 1 is a summary of the tank loads and reduction efficiencies of both BMPs discussed in this report .

Influent and effluent particle-size distributions for MCTT site are reported in Figure 4. Particulate material was comprised mostly of the silt-size fraction (approximately 88%) in both the influent and effluent. Somewhat surprising was the fact that there was no appreciable shift in the particle size distributions between the influent and effluent. Though a decrease in overall particle size would be expected, the size actually increased slightly in the treated water (although the difference was not statistically significant). This fact may suggest that the unit is not selective in the size of particles removed. Another possibility is that material from the filter media, such as sand fines, had escaped around

Table 1. Tank Mass Loads and Efficiencies of the Studied BMP's

Constituent	MCTT Load-in	MCTT Load-out	MCTT % Eff.	Stormceptor® Load-in	Stormceptor® Load-out	Stormceptor® % Eff.
TSS	18.3 kg	0.30 kg	98	1420 kg	1040 kg	26
TDS	84.3 kg	73.3 kg	13	37,500 kg	44,700 kg	-19
Total P	19.3 g	2.4 g	88	1.60 kg	1.29 kg	20
Dis. P	0.93 g	0.20 g	78	0.44 kg	0.34 kg	23
Total Zn	11.7 g	1.0 g	91	660 g	520 g	21
Dis. Zn	1.03 g	0.33 g	68	110 g	105 g	5
Total PAH	0.64 g	.039 g	94	67 g	42 g	36

or through the filter fabric. (Pitt et al. 1997) also noted a slight increase in TSS concentrations as the water passed through the filter tank of their pilot-scale unit. Therefore the unit may still be removing larger particles that are subsequently replaced by media material, resulting in no net change in the distributions. It is important to emphasize that even though there was no appreciable shift in particle size distribution, there was still a very high removal of all particulate material (i.e. suspended solids load) in all storms.

Cost-Effectiveness of the Two BMPs

Though the economics of implementing these BMPs was not the focus of this evaluation, it is an important issue to water quality managers, so a brief cost analysis is offered below. Though actual construction costs for the MCTT were $72,000 ($360,000/acre), some of this high cost had to do with contractor's uncertainties in building an unknown device, retrofitting around existing sanitary sewer, and addition of reinforcements for heavy truck traffic. A similar device was built in Minocqua, Wi. for $95,000 ($38,000/acre) which is only a tenth of the cost per acre. Table 2 presents some estimated costs-per-pound of suspended solids removed for the two management practices. Clearly a number of assumptions were required to generate these numbers. Depending on the location and scale, there can be considerable variation in capital and maintenance costs and control efficiencies. For many practices, long-term studies of removal efficiencies have yet to be conducted. Therefore caution must be observed when making these simple comparisons. Even though the MCTT capital and maintenance costs were higher, this was offset by high efficiency of the unit. For the two BMPs studied, the costs per pound of TSS were of the same magnitude.

Summary

This study evaluates the water quality benefits of two retrofit BMPs, the Stormceptor and the Multi-Chambered Treatment Train (MCTT). Both units were placed in public works maintenance yards where automated sampling equipment collected event-mean concentration data. The Stormceptor treated 91% of the total storm volume from 45 storms. Tank reduction efficiencies for the three constituents measured in all 45 storms (TSS, TDS and TP) were 26%, -19%, and 20% respectively. The extremely high salt concentrations found in the runoff water at this site may have compromised the unit's treatment ability. Good agreement was found between calculated TSS load going into the tank (from water quality samples) and what was actually found in the bottom of the tank, although there is some indication that larger-size particles may have been missed in the water quality sampling.

The MCTT was designed for a greater level of treatment and the findings here confirm it. Load reductions of TSS and TP were 98% and 88% respectively. Even dissolved constituents such as dissolved phosphorus and zinc had high removal efficiencies (78% and 68%, respectively). Somewhat surprising was the little change in particle size distribution between influent and effluent, which may of been an artifact of filter media escaping the filter fabric. Similar costs-per-pound of TSS removed were estimated for the two BMPs studied.

Table 2. Cost-per-pound of Suspended Solids to Treat One Acre of Parking Lot for Different Management Options.

Practice	Efficiency	Total Cost	Cost/acre/yr[1]	% Control	Cost per pound removed
Stormceptor®	Tank	$60,000	$479	26	$1.83
Overall		“	“	22	$2.18
MCTT[2]	Tank	$95,000	$1185	98	$1.21
Overall		“	“	78	$1.52

[1] Capital costs amortized over 50 years plus annual maintenance cost.
[2] Based on construction cost at the Minocqua site.

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Assessing the Effectiveness of Orlando's BMP Strategies

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Orlando calls itself "The City Beautiful" for many good reasons. It is the number one tourist destination in the nation. It has affordable housing, high employment, and an abundance of cultural and civic amenities. Its natural beauty has been named in recent polls as one of the greatest reasons for choosing Orlando as a place of residence and business. One of the principal elements of its natural beauty is its lakes. Orlando has 86 lakes, either wholly or partially located within its borders.

Prior to the mid-1970s there were few regulations which protected these lakes. For decades, storm sewers were installed to convey untreated stormwater directly into lakes. Drainage wells were dug for flood protection. These wells linked untreated runoff with the surface underground aquifer, a source of drinking water for many. It was not until the 1970s that it became apparent that stormwater runoff entering the lakes was causing problems to the natural systems.

The lakes, around which some of the most beautiful and oldest homes in the city were built, were showing stresses from decades of stormwater pollution. Symptoms as small as an overabundance of aquatic weeds and as large as massive fish kills indicated that the lakes were reaching their limit of assimilating the influx of contaminants found in stormwater. To address such problems, the city has taken measures to control stormwater pollution and to provide lake enhancements, drainage well protection, and shoreline revegetation.

The Orlando City Code states, in part that, "... the purpose of the Stormwater Utility Bureau and in essence, the stormwater management program of the city is to 1) improve the public's health, safety and welfare by providing for the safe and efficient capture and conveyance of stormwater runoff; 2) authorize the establishment and implementation of a master plan for storm drainage including ... management, operation,... inspection and enforcement; and 3) encourage and facilitate urban water resources management techniques, including ... enhancement of the environment." Orlando's Public Works Department, with its Bureaus of Stormwater Utility, Engineering, Streets, and Drainage, and Project and Construction Management, work to see that these stormwater management goals and issues are successfully addressed.

The Public Works Department's Stormwater Priority Projects List and the Stormwater elements of the city's Growth Management Plan and the Capital Improvement Plan reflect projects which address qualitative (environmental) issues as well as quantitative (flooding) issues.

BMPs are the methods by which qualitative issues are being addressed. A BMP, or a best management practice, is generally defined as the most effective, practical means of preventing or reducing the amount of pollution generated by non-point sources, such as stormwater runoff, to a level compatible with water quality goals. A BMP should take into account problem assessment, outcome alternatives, public input, and technological, economic, and institutional considerations. The city incorporates BMPs routinely. Some are very basic, while others are more complex. Examples of BMPs utilized by the city include:

Street Sweeping - Street sweeping can be a useful BMP incorporated by a city. Street sweeping removes pollutants, sediments, leaves, and debris from the street surface before they can be flushed into a receiving water body. Orlando sweeps over 40,000 curb miles per year. There are 72 residential routes, seven industrial/commercial routes, and five downtown/near downtown routes. Over 27,000 cubic yards of material is removed annually by the street sweeping program. This material is taken to a landfill for disposal instead of being washed off of the streets in stormwater and deposited into the city's lakes.

Retention/Detention Ponds - In 1984, the City of Orlando implemented rules contained in the *Orlando Urban Stormwater Management Manual* and became one of the first Florida municipalities to require both retention and detention facilities for new development. Under these rules, developers must physically separate the retention volume from the detention volume in what are referred to as "two pond" systems. All development must include pollution abatement capabilities to treat either 1/2 in. of runoff or runoff generated by a one-inch rainfall, whichever is greatest. Treatment is defined as 1) retention with no discharge and/or 2) detention with an approved filter discharge. A detention facility for a developed site must be capable of controlling the runoff volume expected from a 25-year frequency/six-hour duration storm. Detention volume may be discharged, but only at a rate not to exceed the peak rate of discharge of the site prior to development.

Lake Revegetation - Twenty-two miles of shoreline in 45 of the city's lakes have been planted with native aquatic plants. Revegetation returns the lakes to a more natural state and better enables lakes to assimilate nutrient inputs. This also provides valuable wildlife habitat. Lakefront property owners are also encouraged to plant native aquatic plants. City staff believe that revegetation enhances lake aesthetics and water quality. Plantings are required in wet detention facilities. These ponds are shaped with a littoral shelf to facilitate plantings.

Pollution Control Devices (PCDs) - Pollution Control Devices are screening structures that are placed at stormwater outfall pipes to prevent trash from entering the lake. The City of Orlando has installed over 250 PCDs. Cleaning debris from the PCDs after large storms is important and very labor intensive. If the PCDs are not cleaned out, the buildup of leaves and debris can cause the device to be "blown out" by heavy rainfall events, thereby requiring maintenance and repair.

The most unique PCD the city has is a trash collection device recently installed at one of its largest outfalls. At Lake Rowena, a 108" outfall delivers the runoff from a 844 acre drainage basin. Debris that is flushed through this system is so extensive that the normal screening processes became ineffective in medium storm events. Therefore, the city borrowed from the wastewater field and installed flow-actuated moving bar screen (constructed 20 feet below the ground) to intercept debris prior to discharge into Lake Rowena. As flow, and thereby debris, begins to move through the system, the moving screen begins to operate. The screen catches debris, lifts it up, and deposits it into a hopper. The hopper is periodically vacuumed using vactor truck.

Removal of the trash and debris is only the first line of defense in the struggle for pollution abatement. To combat the other deleterious effects of stormwater, runoff has to be treated. The City of Orlando has incorporated many innovative BMPs to treat stromwater, most with great success.

Notable examples of innovative BMPs used by the city include alum treatment systems installed at four of the city's lakes, a Vertical Volume Recovery System, a Packed Bed Filter Project, an Urban Wetland Systems at Lake Greenwood and the La Costa canal, and the Lake Wade Periphyton Filter Water Garden.

Lake Dot Alum Treatment System - Lake Dot is a small (6 acre) lake in downtown Orlando, with a drainage basin of almost 300 acres. The lake had received untreated runoff from this highly developed watershed for decades. Largely as a result of the influx of pollutants during rain events, the lake had experienced periodic fish kills due to low dissolved oxygen. In 1988, construction of the Orlando Arena (home of the NBA's Orlando Magic) within the Lake Dot drainage basin was being planned. When considering measures to meet the city's stormwater treatment requirements, planners first considered surface retention/detention ponds. Because the cost of acquiring land needed for constructing the ponds was prohibitive, an alternative approach was selected in which alum (aluminum sulfate) is added to stormwater to tie up nutrients and suspended solids and precipitate them to the bottom of the lake. Since 95% of all runoff input enters Lake Dot through a single storm sewer line, the same line that the Arena retention ponds would have used as a discharge point, it was determined that the entire amount of stormwater conveyed through this line could be treated with alum. This system has been in operation since 1989, and with the exception of a few operation difficulties, has operated satisfactorily. Improvements to water quality have been significant. Prior to installation of the Alum Treatment System, the lake had been eutrophic, with a Trophic State Index (TSI) averaging over 60. Since the installation of the system, Lake Dot has been classified as mesotrophic, with a TSI average of just over 50.

The success at Lake Dot has encouraged the use of alum treatment at other locations. Alum treatment systems have been installed at Lake Lucerne in downtown Orlando, Lake Holden (as part of a joint project with Orange County), and Lake Rowena. An alum treatment system is currently being planned for Clear Lake.

The Vertical Volume Recovery System - The Vertical Volume Recovery System (VVRS) combines in-pipe storage, a sump device for sediment removal and a sand filter for fine sediment and dissolved pollutant removal. The stormwater treatment system was developed as a part of an inter-basin diversion plan needed to relieve flooding from Lake Olive, one of our downtown lakes. The system was designed to treat one inch of runoff from the roadway surfaces within the basin area. It was believed that the sand filter would be an effective method of stormwater treatment where land is too expensive for standard retention/ detention. To date, the VVR Ssystem has been a maintenance burden. The treatment capabilities of the sand filter have been disappointing.

Monitoring results showed some removal of dissolved and particulate pollutants within the sump device. The sump removed lead at rates between 50 and 78%. Zinc was removed at rates between 40 and 56%. Cadmium was removed at 50 to 60%. No significant removal of other heavy metals was observed. Total Kjeldahl Nitrogen (TKN) was removed at rates ranging from 14 to 56%. Total phosphorus was removed at rates from 29 to 51%. Total suspended solids were removed at rates between 14 to 71%.

Monitoring results also showed very poor removal of dissolved and suspended pollutant types by the filter. Removal was 3% for copper, 5% for nitrate-nitrite, 10% for total phosphorus and 12% for suspended solids. Export of pollutants was observed at 10% for lead, 248% for ammonia, 2% for TKN and 19% for orthophosphate.

The Packed Bed Filter Project - A Packed Bed Filter Project at Clear Lake has proven to be very successful. The idea of using vegetated rock media filters to treat stormwater was proposed in response to growing concern over the water quality of Clear Lake. Clear Lake, once a lake that was clear, had become eutrophic by the early 1980's, and was one of Orlando's poorest quality lakes.

The Clear Lake drainage basin consists of over three square miles of highly developed urban area. Stormwater runoff from this basin is conveyed into Lake Beardall and Clear Lake. The Packed Bed Filter treats the initial storm runoff from about 160 acres. Because the project demonstrated an innovative technology, the city was successful in obtaining a grant from Florida Department of Environmental Protection (FDEP). The project uses a proven wastewater technology to urban stormwater pollution. Simply put, the system consists of a packed bed filter, similar to a trickling filter, and hydroponic aquatic plants.

Ten beds were established, including five crushed concrete and five using granite. Four different types of native aquatic plants were planted in four of the concrete and four of the granite beds. Two beds were set aside as controls. Assessments were performed on the effectiveness of the overall packed bed filter system, the performance of the individual beds, and the best rate at which to operate the system.

Monitoring results indicated medium to high effectiveness in treating stormwater. Total phosphorous, total suspended solids, and volatile suspended solids and cadmium were removed by the overall packed bed system at a rate exceeding 80%. Total nitrogen, TKN, nitrates, nitrites, chromium, copper, lead, and zinc were removed at rates ranging from 25 to 80%. Removals of ammonia, orthophosphate and total dissolved solids were not as effective, with only 6, 14, and 8% removal, respectively.

The Greenwood Urban Wetlands - What was initially conceived as a flood protection project, ended as a multipurpose, multi-use facility. Florida's first stormwater treatment train was created to provide stormwater quality improvement, address the need for additional park area, and provide flood protection for a 522-acre drainage subbasin. The project required the expansion of Lake Greenwood to over six times its original size. It also involved planting over thirteen acres of wetland and upland vegetation, and constructing footpaths, bridges, and stormwater control facilities. In addition to these features, the new man-made wetland includes a pumped irrigation system which utilizes stormwater runoff, instead of potable water to irrigate the park and a neighboring city-owned cemetery. FDEP provided a grant to determine the effectiveness of the created wetland stormwater treatment. The results were very good, and would likely have been even better had it not been for a high rate of groundwater inflows. This award winning project os one of Orlando's most significant stormwater management success stories.

This Greenwood project has proven to be a success in all areas it had been intended. It provides flood protection, stormwater treatment, a much-needed passive park, and stormwater reuse through irrigation. The city has repeated this concept, on a slightly smaller scale, with the construction of another urban wetlands, the La Costa Urban Wetlands.

Periphyton Filter Water Garden at Lake Wade - This joint venture project with the St. John's River Water Management District will demonstrate the effectiveness of a managed growth periphyton filtration system. The Periphyton Water Garden is a stair-stepped concrete structure with a surface that fosters the growth of algae. Water from Lake Wade is pumped to the top of the structure and flows over the algae and back to the lake. The algae consume nutrients and traps sediment. Each week, the algae are harvested from the water garden and trucked away from the site. The algae biomass can be used as an environmentally friendly packaging material or be spread on park grounds or ballfields as a fertilizer.

Periphyton, or attached algae, comprise the most productive component of a wetland system. The Periphyton Filter accelerates natural algae growth processes in a controlled farmed system. A periphyton filter delivers a thin sheet of untreated water over a diverse community (100-200 species) of attached algae. Since techniques and devices developed for harvesting the algae leave "roots" intact, rapid regrowth occurs. Algal species diversity and frequent harvesting make periphyton filters adaptable to changing conditions, for consistently high productivity.

Periphyton Filters work on a wide range and various levels of contaminants. Particularly interesting is their ability to function at extremely low levels of pollutants, which lends itself to lake restoration and treatment. The periphyton filter is a promising approach to reducing non-point source pollution in Lake Wade.

This project went on-line in December, 1997. The Water Management District and the City will be conducting research and monitoring during 1998 to determine its effectiveness.

Orlando is a leader in developing innovative approaches to stormwater treatments for quality and quantity control. The City of Orlando is very proud of its stormwater management practices.

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Evaluating Public Information Programs: Experiences with the Florida Yards and Neighborhoods Program

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This report provides an overview of the evaluation methods applied to the Environmental Landscape Management (ELM) and Florida Yards and Neighborhoods (FYN) programs of the University of Florida's Cooperative Extension Service. Florida Yards and Neighborhoods is a public education component of the major state-wide Environmental Landscape Management program.

The Homeowner Research Questionnaire has been a useful tool in measuring the level of adoption of environmental landscape management practices by different program groups. County-based surveys are used to show overall program effectiveness and to compare different program delivery methods. A 1997 analysis by the University of Florida comparing three delivery methods used throughout Florida, indicated that educational seminars are an essential component in helping people adopt ELM practices.

Social marketing research conducted in 1997 studied the perceptions that Tampa Bay homeowners have regarding environmental landscape management practices. This research included pre- and post-test evaluations of educational materials used by Florida Yards and Neighborhoods.

In this report, a brief overview of the ELM and FYN programs will provide the foundation for discussing the evaluation. This overview is followed by a description of two ELM/FYN evaluation methods. This paper summarizes, in part, two reports prepared in 1997: *Adoption of Landscape Management Practices by Florida Citizens*,[1] by Glenn D. Israel, Janice O. Easton and Gary W. Knox; and *Social Marketing Study of the Perceptions Tampa Bay Homeowners have Regarding Environmental Landscape and Protection Practices*,[2] by Bonnie Salazar. Both are cited at the end of this paper. The concluding section will look at lessons learned and future plans for measuring program effectiveness.

Introduction

Evaluating community-wide environmental education programs is essential to measuring the effectiveness of outreach efforts. Determining program effectiveness not only aids in refining educational tools, it is often essential for obtaining or maintaining funding. However, measuring changes in awareness, knowledge and behavior presents a variety of challenges.

Those implementing community-based educational programs do not have the advantage of a captive audience who must come to class and turn in assignments. In fact, getting the target audience to respond to measurement techniques is one of the biggest challenges of all, even if it is a list of questions about their yard design and care practices.

Overview of ELM and FYN

Environmental Landscape Management was developed in the late 1980s to educate professionals and homeowners on how to create attractive, healthy landscapes by taking an ecosystem approach to landscape design and maintenance. "Right plant, right spot" is the key tenet. Educational materials emphasize adopting proper cultural practices to reduce landscape problems and negative impacts on the environment.

Florida Yards and Neighborhoods is a component of the ELM major state program. Developed in partnership with the Sarasota and Tampa Bay Estuary Programs, FYN increased the emphasis on the problems of stormwater runoff pollution and the need to protect estuary systems. Since its implementation in 1992, Florida Yards and Neighborhoods has expanded its scope to include freshwater systems.

A variety of educational tools have been developed for the Florida Yards and Neighborhoods Program, many of them initially funded by the Sarasota Bay and Tampa Bay National Estuary Programs. As the program continues to develop, the need for additional tools becomes apparent, as does the modification of some of the existing ones. A continuing goal for those involved in the FYN Program is obtaining the funds to purchase existing materials and develop new ones.

A Guide to Environmentally-friendly Landscaping: The Florida Yards and Neighborhoods Handbook[3] (Florida Cooperative Extension Service, 1994) is in its third printing. *The Florida YardStick Workbook*[4] (Florida Cooperative Extension Service, 1998)[4] supports the handbook by providing a checklist of environmentally friendly landscape design and care actions that are discussed in the book. Two slide presentations demonstrate ELM/FYN practices and discuss the benefits of adopting them: "Creating Your Florida Yard" and "Maintaining Your Florida Yard." The FYN message is presented in video form through the half-hour *Reclaiming Paradise: Florida Yards and Neighborhoods*.

Various national estuary programs in Florida have provided funding to implement the FYN program in their counties. The purpose of this short-term funding was to help establish a successful program that local government entities would use to help meet their goals of water conservation and reduced stormwater runoff and solid waste. Program evaluation plays an important role the continuation of an FYN Program in a county.

Program Evaluation Approaches

Program evaluation has always been an important component of the Environmental Landscape Management Program. A self-report survey using the Homeowner Research Questionnaire is the primary state-wide evaluation tool. In 1997, a social marketing research project provided additional methods, on a regional basis, for measuring and increasing program effectiveness.

The Homeowner Research Questionnaire Survey

The Homeowner Research Questionnaire measures the number of environmental landscape management practices the respondent is using. Participants complete the pre-test questionnaire prior to receiving an educational program or educational resources. Ideally, the post-test questionnaire is completed six months later. Comparisons of pre- and post-test responses measure changes in behavior.

The pre-test questionnaire contains the following categories: General Information, Site Analysis, Stormwater Runoff, Irrigation, Fertilizer, Pest Management, Wildlife, Information Sources and Waterfront. With the post-test questionnaire, the Information Source category is dropped and questions are added under the new category "Views on FYN Practices." Landscape practices include using slow-release fertilizers, applying one pound of nitrogen or less per 1,000 square feet, leaving grass clippings on the lawn, tolerating some pest damage, watering according to season and directing downspouts into the lawn or plant beds.

Each questionnaire is coded according to the type of program the participant received. Program types can include the following: neighborhood program, all-day workshop, one-hour presentation, exhibit, and Master Gardener training. In some counties, people also receive publications by coming into the Extension Service or by calling and requesting information. This category is referred to as "Publications only."

Each county enters its own data using a standard template. The data is sent by computer disk to be analyzed by the Program Development and Evaluation Center of the Institute of Food and Agriculture Services, University of Florida. Counties use the survey data to evaluate different delivery methods and in their annual reports to funding sources. Because the program content and landscaping practices taught among the counties are consistent, state-wide comparisons of delivery systems can also be made.

In 1997, the University of Florida Cooperative Extension Service conducted a state-wide comparisons of three ELM/FYN program delivery methods: Master Gardener training, 1-6 hour seminars and publications only.[1] A control group was composed of non-participant residents who completed the ELM Homeowner Research Questionnaire in 1993 to establish a baseline. The data for the program delivery groups was collected immediately prior to and approximately six months following educational programs conducted during the 1997 Fiscal Year (July 1, 1996 through June 30, 1997.)

This study looked at average adoption rates in the different groups, as well as the adoption rate for specific landscape design and care practices. However, this paper will discuss only the findings regarding overall adoption rates.

The Master Gardener group data was collected from 134 residents in nine counties. Three hundred and twenty residents in six counties contributed the data for the 1-6 seminars group. In two counties, data were collected from 72 residents who received publications only. The Master Gardeners had the highest response rate, with 63% returning their surveys, compared to a 42% response rate for seminar participants and 57% for the non-equivalent comparison group. This study focused on 39 landscape care and design practices included in the questionnaire.

A comparison of the pre- and post-test survey results indicated an increase in the average number of practices used by participants of all three program delivery methods, while non-participants remained essentially unchanged (Figure 1).

The results of an analysis of variance show that while the type of property, person maintaining the property, presence of a permanent irrigation system and parcel size did not affect the adoption of practices, the type of program did ($F=31$; $p=0.001$). A multiple comparison of adjusted means for net adoption using Fisher's least significant difference indicated that each program type differed significantly from the other groups in the number of practices adopted (Table 1).

Social Marketing Research

Three grants funded social marketing research on the Florida Yards and Neighborhoods/Environmental Landscape Management Programs in 1997. Funding came from

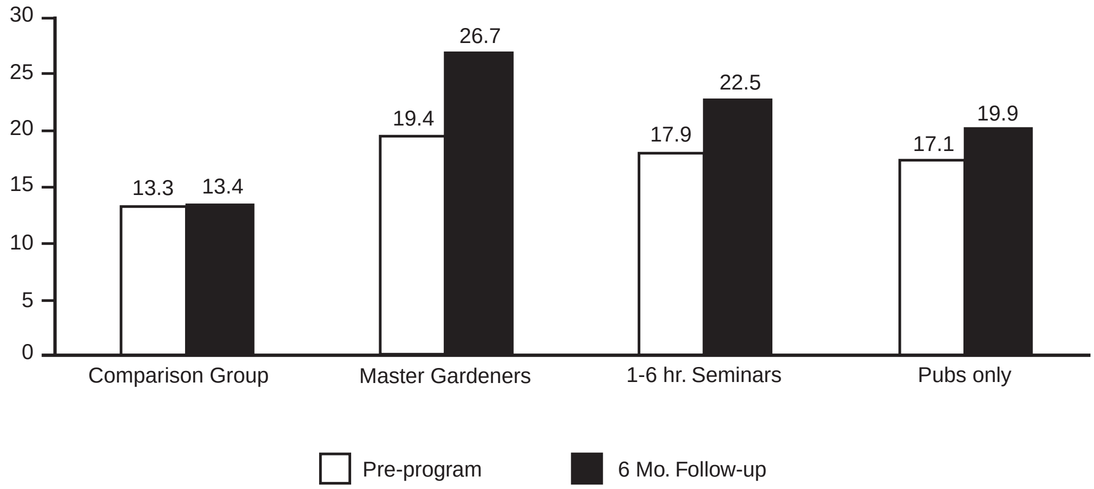

Figure 1. Mean numbers of Best Management Practices used by program type.

Table 1. Average Number of Environmental Landscape Management PracticesAdopted by Type of Program

Type of Program	Mean Number of Practices Used Before the Program	Net Number of Practices Adopted	Adjusted Net Number of Practices Adopted[1]
Master Gardener	19.4	7.3	6.9
1-to-6 hr seminar	17.9	4.5	4.3
Publications only	17.1	2.8	2.6
Comparison group	13.3	0.1	0.0

[1] Model of R^2 of .135 and p=.001. Adjusted means were generated by the analysis of variance for comparison using Fisher's least significance differences.

the following: Florida Cooperative Extension Service; NPDES (National Pollution Discharge Elimination System) Education Subcommittee of the Florida Department of Transportation, District 7; and West Coast Regional Water Supply Authority (WCRWSA). In-kind services, including co-moderating focus groups, were also supplied by the Cooperative Extension Service. The research was conducted by Chastain/Skillman, Inc.

Social marketing adapts commercial marketing technologies to programs designed to influence voluntary behavior that improves the personal welfare of target audiences and their society. The purpose of this research project was to determine the perceptions Tampa Bay homeowners have regarding environmental landscape and protection practices. There was the sense in entering this social marketing research project that there are different consumer groups relative to yard care. It was hoped that the research would help identify those groups by the benefits and drawbacks they perceived in the ELM program. FYN could then target those groups that would be the most receptive by crafting programs to meet their needs.

The research included focus groups, participant-observation, surveys and the pre- and post-testing of educational materials. The Florida Cooperative Extension Service, especially the Hillsborough County office, coordinated the effort and provided in-kind services. This paper will look at the pre- and post-testing of program materials.

The *Florida YardStick Poster* was introduced into the Florida Yards and Neighborhoods Program in 1994. This colorful poster groups important yard care and design practices (or actions) into seven categories. Each Florida Yard action is worth a given number of inches (or credits) and once a homeowner has accrued 36 inches or more, his or her yard can be certified as a Florida Yard. The poster is 38 inches tall by 24 inches wide.

The poster was useful in classroom and workshop settings. It graphically showed the relationship between taking action and creating an environmentally friendly Florida Yard. However, there was some question as to its usefulness as a tool for homeowners. There was a suggestion to turn the poster into a workbook format—keeping the actions, but changing the format and adding practical "how-to" information to augment the handbook's general principles.

It was decided to conduct a post-test evaluation of the workbook during the initial focus groups conducted as part of the social marketing research. Toward the end of the focus group meeting, participants were asked to look at the poster and respond to questions about its appearance, usefulness, intended audience, etc. After the general discussion, participants were given sections of the poster to evaluate. They wrote their comments and questions about the section they received.

In general, participants said the design was friendly and cheerful. It was noted that for a poster, the print should be larger. Often, when asked who the intended audience was, participants said they thought it was for school children. Some said they would hang the poster in their garage as a reference. A frequent suggestion regarding format was to change it into a booklet format. Recommendations regarding text included minimizing the use of technical terms. Participants indicated that words such as "low-maintenance," "irrigation," "least toxic," and "pervious" were hard to understand.

The Florida YardStick Workbook incorporated the colors and graphics used in the poster because of the positive reaction people had to these elements. The book was sized to fit into the back flap of the FYN Handbook. The basic concept of the poster, with the categories and actions was maintained. A major change was in the use of terminology. When possible, technical terms were replaced with more common terms. For example, "water sprinkler" replaced "irrigation system."

The pre-test evaluation of *The Florida YardStick Workbook* was conducted using the first draft of the workbook. Because of time restrictions, the pre-test was not done in focus groups. Instead, through one-on-one interviews, people seeking to enter Master Gardener training were asked about their perceptions regarding the workbook.

Again, the general response was that the overall appearance is attractive and friendly. Participants found the information useful and the writing easy to understand. Many recommended that a larger print size be used. A common complaint was that the pages looked cluttered.

In response to these observation during the pre-test evaluation, a larger print size was used and more white space was added. Because of cost constraints, information was condensed or deleted. However, this process of honing the content helped define critical elements.

Conclusions

Public information programs are viewed as an essential component in helping to reduce stormwater runoff pollution, conserve water resources, protect wildlife habitats, and engage in other environmental protection actions. Evaluating environmental information programs is a challenging but essential process for determining the effectiveness of various strategies, for developing new approaches and for justifying new, additional or continued funding.

In 1997, the University of Florida Cooperative Extension Service used two evaluation methods with its Environmental Landscape Management Major State-Wide Program, which also encompasses Florida Yards and Neighborhoods. The ELM/FYN Homeowner Research Survey proved to be a useful tool for comparing the effectiveness of three different program delivery methods. Taking a social marketing approach to evaluating educational publications was a productive method for making them easier to read and comprehend.

Of course, it is important to evaluate the evaluation mechanisms. The ELM team is currently in the process of refining the ELM/FYN Homeowner Research Questionnaire. Currently, the questionnaire measures changes in self-reported behavior. An important question is to what extent does that behavior change result in water conserved, reduced nutrient runoff from yards, a decrease in the use of toxic pesticides, or other quantifiable results? Therefore, one goal in revising the questionnaire is developing queries that can result in valid, quantifiable answers.

Another reason to have an ongoing process of evaluating the evaluation techniques is that new research results regarding stormwater runoff pollution or other environmental issues may lead to new goals for public action. For example, early educational efforts in public information programs regarding stormwater runoff pollution focused on having homeowners reduce their use of fertilizers and pesticides and keep their driveways and street gutters clean. However, with research showing the increasing importance of atmospheric nitrogen deposition, we may want to focus on additional behaviors, such as increasing public support for stormwater retrofit projects, street cleaning, and mass transportation.

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Examining the Need for Project Evaluation

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Abstract

Retrofit project evaluation is as critical as project goals and objectives. Formulation of a project evaluation should begin when the project begins; it is an essential part of the planning process. Without an evaluation system in place, it is likely that you will waste precious time and funding. Many assume that evaluations are expensive and require extensive expertise. Sometimes this is true, but there are easier and less expensive approaches that can be used, if you accept the tradeoffs that come with a less complicated evaluation method. Evaluations make it easier to make a decision and justify your choices. This article presents the role of evaluation, describes several types of evaluations and provides examples.

Introduction

Too often project evaluations are scheduled at the end of a project, and incompletely determine whether the goals and objectives have been met. Evaluations should instead be an ongoing part of any retrofit project or program (henceforth project means both project and program). The typical project, designed to accomplish a specific task, is commonly evaluated by the completion of just that task. In addition to accounting for whether specific activities are being implemented, and resources expended, evaluations need to be designed so as to determine the impacts over the whole project. One should also evaluate the broadest impacts caused by completion of the task. For example, a recent outreach program to developers and homebuilders focused on ways to achieve development and still protect wetlands. The program was evaluated only by the number of presentations, the amount and type of material distributed, and the requests for information. The program was not evaluated against wetland loss prevented, so the program's entire impact was underestimated.

Most completed nonpoint source project evaluations are inadequate. Many projects do not even include an evaluation. In a study on river conservation enhancement, Holmes (1991) found that only five of almost 100 projects had post-restoration evaluations. The most common excuses given for not carrying out evaluations were time, cost, "evaluations not worth it" and "evaluations are difficult."

Most completed evaluations also fail to determine whether the project had the long-term impacts it was designed for. For example, most monitoring associated with nonpoint source control projects focuses on the number of Best Management Practices (BMPs) implemented, and stops when implementation funds have been expended. The Rural Clean Water Program (RCWP) showed the importance of lag time between when BMPs are implemented, and when water quality changes (USEPA, 1993). Linking project evaluation to BMP implementation funding creates an inherent bias toward failure to demonstrate water quality improvements, because it may take years between BMP implementation and the realization of water quality improvements.

In response to this lag problem, and the need to have a national evaluation on the effectiveness of the Section 319 (Nonpoint Source) Program (EPA, 1991), the United States Environmental Protection Agency (USEPA) created the Section 319 National Monitoring Program. That program established frameworks to more carefully document water quality impacts associated with selected BMP implementation, especially over a longer period of time than usual. The National Monitoring Program's objectives are1) to scientifically evaluate the effectiveness of watershed technologies designed to control nonpoint source pollution, and 2) to improve our understanding of nonpoint source pollution (USEPA, 1991). For more information on the National Nonpoint Source Monitoring Program see Osmond, et al. (1997).

Why Evaluate?

While evaluation is both an art and science, it is critical to the long-term success of any project. Project evaluations allow managers to build on success and learn from mistakes. Beech and Drake (1992) say it best; "Would you invest your own money knowing that you would not get any feedback on performance of the investment?" Without an evaluation system for your project, you could be wasting time and money and not know it. The Highland Silver

Lake RCWP Project is an excellent example of why evaluations are essential to the success of a project. Designed to address lake sedimentation, the project's monitoring and evaluation efforts showed that the lake was instead being impacted by natric soils (causing high turbidity levels) and not excessive sediment loading (Davenport & Kelly, 1986). Evaluation systems can also play an important role in linking your activities to the public and gaining their support.

Evaluation Types

Evaluations can be done at different stages during a project, or at multiple stages. There are many evaluation methods, techniques, and approaches designed for specific purposes and project phases (planning, implementation, and evaluation). A comprehensive evaluation will utilize a combination of these methods to accurately evaluate a project. The four major types of evaluations are Formative, Process, Outcome, and Impact. After discussing these in the next paragraphs, we will continue with discussion of more modest forms of evaluation.

Formative Evaluation (before the project starts) - A formative evaluation is undertaken to test approaches, materials, and ideas. Additionally, formative evaluations are used to understand the target audience before a project is implemented. For projects involving communication, a key factor is determining the appropriate target audience, based on project goals and objectives. A second sort of formative evaluation is a needs assessment. The principal difference between the traditional formative evaluation and needs assessment involves the decisions that arise from the outcomes. According to Herman and others (1987), needs assessments result in better allocation of resources to meet high priority needs. The formative evaluation is an attempt to improve implementation prior to getting started. For example, school materials about wetlands might be selected by an advisory group of experienced teachers. Or, land owners could be surveyed concerning barriers to adopting conservation practices.

Process Evaluation (during)- While some consider this part of a formative evaluation, for this paper it is separate and focuses on tracking activities. Bean-counting is another phrase for this type of evaluation. Using process evaluation, managers can monitor implementation activities and provide timely information to their staff and project sponsors. Process evaluations allow managers to change project activities in response to ongoing feedback. Major problems in using process evaluations for nonpoint source projects include the inability of process evaluations to determine the cause of the problem (before implementation begins), and the lag time between implementation and reporting of accomplishments. Process evaluations can 1) monitor the program activities by recording activities systemically, 2) keep everyone focused on the big picture, and 3) provide a database to allow project managers to evaluate cost-effectiveness at every stage of the project. Examples of process evaluation are tracking BMP implementations and requests for technical assistance.

Outcome Evaluation (afterwards) - This is also referred to as a "summative" evaluation and measures the short-term results associated with a project. The big question, "What did I get for my money?" gets answered here. Outcome evaluations can be used to 1) measure changes in knowledge, attitudes, awareness, skills, aspirations (KASAs) or behavior, 2) determine whether the project worked within the desired time frame, and 3) determine whether the project goes beyond the desired effects. An example would be a workshop evaluation that focuses on participant changes, or the USEPA Region 1 review of their Section 314 Clean Lakes Projects (Metcalfe & Eddy, 1992).

Impact Evaluation (much later)- Impact evaluation is the most difficult type of evaluation to complete. It measures long-term impacts. This type of evaluation requires durability of project goals and objectives. It is important to note that the world keeps changing as your project progresses, so evaluators must determine whether the project's goals and objectives have remained constant. Longer-term results usually vary from short-term results, so impact evaluation is needed to measure the ultimate value of the project. This type of evaluation is extremely important for pilot and demonstration projects. Many programs are developed and implemented based on either "process" or "outcome" evaluations of pilot or demonstration projects and lack real impact evaluation.

EPA's Clean Lakes Program (Clean Water Act Section 314) stresses evaluation through all three phases: Diagnostic, Implementation, and Post Restoration. Phase 1 evaluations should be the least complex (formative and process), while Phase 3s are more complex (impact evaluations that provide individual outcomes and future direction). One Phase 3 Post-Restoration Monitoring study was conducted five years after the successful completion of a Phase 2 lake/watershed management program designed to eliminate watershed sources of pollutants to Lake Le-Aqua-Na and improve in-lake water quality. Phase 2 of the project was judged a success after evaluation indicated the project met its immediate goals and objectives. The Phase 3 study, five years later, confirmed that the BMPs were still in place, that the effectiveness of some of the BMPs had decreased but were still achieving their goal, and that the overall management program was still having the desired effect on the lake (Davenport & Kaynor, 1998).

Clean Lakes Projects and Nonpoint Source Control Projects are similar in that they rely on changes in human behavior, but the basis of determining which changes are needed is different for each. Proposed changes in Clean Lakes Projects are based on stakeholder-involved diagnostic/feasibility studies. Nonpoint Source Project changes are usually prescribed based on preconceived or documented problems without stakeholder input during the formulation phase. This is an important difference which needs to be considered in all outcomes or impact evaluations.

In Clean Lakes Projects, landowner/operator education efforts start during Phase 1, their reactions and KASA levels are designed into the Phase 2 implementation plan. With Nonpoint Source Projects, landowner/operator reactions and KASA levels are used to modify the implementation plan after it is underway. When a Clean Lakes or Nonpoint Source Project is promoting BMPs, evaluating education being used is especially critical to accomplishing long-term behavior changes. Too often NPS projects judge success only by the number and types of BMPs that landowners/operators are willing to install. Long-term maintenance and operation are seldom considered within Nonpoint Source Project evaluations, but are a major focus of Phase 3 Clean Lakes Projects.

Evaluation Components

There are many different evaluation components available for Nonpoint Source Project evaluation (Table 1).

A brief summary (modified from Beech & Drake, 1992) of each of the Hierarchy's components follows:

1) Inputs - Project resources that are used to carry out the work. These resources include, at a minimum, funds, paid staff, volunteers, office space, and supplies.

2) Activities - Actions that are done, to implement the work, such as planning.

3) Target Audience - Identifying who the target audience is for the project, and how they influenced project design and implementation.

4) Reactions - Reactions of the target audience to the project activities.

5) KASA Change - The project's activities must change either the knowledge, attitudes, skills, or aspirations of of the target audiences (participants) to get implementation.

6) Changes in Behavior - Participant behavior changes through the implementation process.

7) End Results- Results compared to the goals and objectives developed when the activities were planned.

A modification of Bennett's Hierarchy of Evidence for Program Evaluation is very relevant to Nonpoint Source Projects (Table 2).

Evidence of real impact becomes stronger as the evaluation ascends the hierarchy. The two lowest levels (inputs and activities) provide little or no measure of participant benefit or environmental improvement. Level 3 provides the first opportunity to get an indication of educational possibilities. If a focus of the evaluation is to increase project performance, it is important to apply more evaluation techniques at the lower levels (3 and under). Thorough assessment of project effectiveness requires evaluations to be conducted at the upper levels of the hierarchy. Evaluations covering Levels 4 (Reactions) and 5 (KASA) provide an indication of whether or not the activities are working. KASA changes give an indication of potential BMP adoption. External accountability increases as the level of evaluation increases, while internal accountability follows the reverse trend. Since the project is likely to change as it develops, project evaluation techniques selected for higher levels of the hierarchy must be flexible enough to respond to change.

Table 1. Bennett's Hierarchy of Evidence for Program Evaluation (Beech & Drake, 1992)

Level	Component
7 (highest)	End Results
6	Behavior Change
5	KASA Change
4	Reactions
3	Target Audience
2	Activities
1 (lowest)	Inputs

Table 2. Modified Bennett's Hierarchy

Level	Component
7 (highest)	Behavior and Resulting Environmental Change
6	End Results (linked to funding period)
5	KASA Change
4	Reactions
3	Target Audience
2	Activities
1 (lowest)	Inputs

The level at which an evaluation is carried out (i.e., 1 to 7) has a tremendous impact on cost, requirements, and useability. The higher up the hierarchy, the greater the probability that project results will be influenced by external factors which are more difficult to evaluate. The evaluations that utilize the higher levels of the hierarchy usually involve more expensive data collection and more time to obtain results. Also, more expertise is required to design evaluations, analyze data, and provide feedback. In addition, evaluation techniques require expertise to separate external influences from actual project.

Reversing the order of Levels 6 and 7 is more appropriate for Nonpoint Source Projects. The resulting evaluation then focuses on surrogates for water quality, and completing the implementation plan. This modification allows evaluators to determine if the BMPs are being maintained and operated properly after the agencies have moved on to other priority areas, and whether water quality has improved. It also takes into account the "Hawthorne effect" where participants respond favorably about implementation because of attention rather than commitment to change (when attention has faded they revert to previous behavior). The modification also attempts to link long-term behavior change with long-term changes in the environment that are associated with the behavior in question. The modified Hierarchy, shifts the focus of the evaluation to long-term behavior changes after the implementation of BMPs has been completed.

Table 3 relates the level of evaluation to the type of evaluation. Based on cost and complexity, project managers

Table 3. Modified Hierarchy Levels as They Relate to Evaluation Type

Level	Component	Formative	Process	Outcome	Impact
7	Behavior Changes		X	X	X
6	End Results		X	X	X
5	KASA Change		X	X	X
4	Reactions		X	X	X
3	Target Audience	X	X		
2	Activities	X	X		
1	Inputs	X	X		

must decide what type of evaluation is appropriate to document their overall project or phase. While not all projects need the same level of evaluation, the evaluation should be planned prior to initiation, and not as an afterthought. The level and type of evaluation utilized must be linked to program needs. For example, if the program status is needed, an evaluation that focuses on Levels 1 and 2 of the hierarchy would be sufficient. If, however, program managers are contemplating changing the direction of the program or enhancing specific components, the evaluation must be able to correlate data from Levels 1 and 2 evaluations to target audience (Level 3), reactions (Level 4), KASA (Level 5) and end results (Level 6) for the existing efforts, and what would be expected with future efforts.

Table 4 shows what level of the modified Hierarchy should be addressed during each project phase. Using Table 4, managers can design project evaluations that build from one phase of the project to the next. Again, the Clean Lakes Program is an excellent example of this process.

Based on earlier experiences in agricultural nonpoint source program evaluations (Model Implementation Program, Agricultural Conservation Program Special Water Quality Projects) and the Clean Lakes Program experience, the third generation of USDA's nonpoint source program (RCWP) built evaluation components into the process. The premise of RCWP was that agricultural nonpoint source pollution could be controlled at the farm scale to cost-effectively improve off-site water quality. The Comprehensive Monitoring and Evaluation (CM&E) component of the RCWP was established to document the farm level effectiveness of the program, based on a sample of 20% of the projects funded under RCWP. CM&E Projects were selected for intensive monitoring and evaluation efforts to represent the universe of agricultural nonpoint source problems being addressed. The evaluation framework for RCWP consists of three tracks: 1) individual project monitoring, 2) CM&E projects and 3) national surveys. The individual projects were primarily evaluated in terms of inputs and activities (Levels 1 & 2) outlined in the implementation plans. Attempts were made to link these process evaluations with project outcomes. These evaluations (tracking activities) were carried out by the project technical and administrative staff as part of their ongoing duties. The process evaluations were inexpensive and very straightforward. In some of the individual projects, process evaluations were supplemented by Cooperative Extension Service surveys of the target audience (Level 3) to estimate changes in knowledge (Level 5) and document reactions (Level 4) to the program. CM&E components separately fund (usually more than $1,000,000 per project) staff and work plans; they were integrated as part of the individual projects so the project's technical and administrative staffs were involved in the evaluation but not responsible for it. CM&Es integrated all four types of evaluations in the individual projects over a 10-year period. Formative evaluations were used with the watershed land owners/operators to help determine resource allocations between project components and to establish a baseline (Levels 3 and 4) to document behavior patterns (Level 6) and knowledge levels (Level 5). Process evaluations were used to determine implementation status and direction (Levels 1-4 and 7), and a CM&E water quality sampling program was established to determine the overall impact on water quality (Level 7). Nationally, the CM&Es and other project evaluations were supplemented with statistically based socioeconomic phone surveys of participants and nonparticipants in the project areas. The combination of these three evaluations enabled national program managers and experts 1) to develop a list of recommendations concerning future agricultural nonpoint source control projects (Farm Bureau, 1992), 2) provide guidance to states to help them develop their own programs and 3) to determine the impact of RCWP on watershed level water quality.

Table 4. Hierarchy Levels as They Relate to Project Phase

Level	Component	Planning	Implementation	Evaluation
7	Behavior Changes		X	X
6	End Results		X	X
5	KASA Change		X	X
4	Reactions	X	X	X
3	Target Audience	X	X	
2	Activities	X	X	
1	Inputs	X	X	

A review of the Section 319 Program (which is more recent than RCWP) indicates that states and others have utilized the lessons learned from RCWP to design the next generation of agricultural Nonpoint Source Programs. The RCWP experience shows that ownership of the evaluation 1) increased the useability of the evaluation by the project implementation team, 2) increased the volume and improved the quality of material provided to the public and target audience during project implementation, and 3) decreased the response time between a concern or issue being raised and resolved with project-level data. The CM&E component proved invaluable in the overall evaluation of the RCWP Program.

Evaluation Barriers

In addition to some barriers already mentioned, there are a number of factors that may limit the scope, direction, and success of an evaluation. Leeds and others (1995) developed a list of factors that may influence an evaluation:

Organizational Politics
Organizational Structure

Program Leadership
Professional Influences
Project/Program History
Economics
Social Patterns
Legal Guidelines

Each of these factors has implications for an evaluation. Examine the purpose of a project evaluation in the context of these factors. For example, is the evaluation going to be used to "get" someone (organizational politics)? Knowing which of these factors might have an impact on your evaluation will allow the evaluation team to modify data collection approaches and methods to account for it.

Closing

1) Evaluation should begin when the project/program begins and be part of the planning process.

2) Evaluations that are based on valid information are more useful in decision-making than those based on assumptions or opinions.

3) Evaluations that focus on average conditions and average operations may miss the importance of extremes.

4) Evaluation information that truly reflects the target audience results in better decision-making.

5) Hard data is generally more comfortable as a basis of making project decisions. However, hard data is usually more expensive and time-consuming to acquire.

6) Acceptance of evaluations is more likely when management is involved throughout the evaluation process.

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