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# Seminar Publication

# National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels

March 30 to April 2, 1993

The Westin Hotel

Chicago, Illinois

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**Authors**

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**Peer Reviewers**

The following individuals peer reviewed the papers presented in this document:

Frank Browne, F.X. Browne, Inc., Lansdale, PA
Richard Christopher, Greenville County Soil and Water Conservation District, Greenville, SC
Scott Clifton, Chesapeake Bay Local Assistance Department, Richmond, VA
Thomas Davenport, U.S. Environmental Protection Agency (EPA) Region 5, Chicago, IL
John Ferris, RUST Environmental and Infrastructure, Inc., Milwaukee, WI
Richard Field, EPA Risk Reduction Engineering Laboratory, Edison, NJ
Lisa Jayne Gray, EPA Region 5, Chicago, IL
Marlene Hale, Chesapeake Bay Local Assistance Department, Richmond, VA
Judy Kleiman, EPA Region 5, Chicago, IL
Norm Kowal, EPA Environmental Criteria and Assessment Office, Cincinnati, OH
Jim Kreissl, EPA Center for Environmental Research Information, Cincinnati, OH
Ernesto Lopez, EPA Region 5, Chicago, IL
Daniel Mazur, EPA Region 5, Chicago, IL
Belinda Montgomery, EPA Region 5, Chicago, IL
Timothy Neiheisel, EPA Environmental Monitoring Systems Laboratory, Cincinnati, OH
Thomas O’Conner, EPA Risk Reduction Engineering Laboratory, Edison, NJ
Linda Papa, EPA Environmental Criteria and Assessment Office, Cincinnati, OH
Nancy Phillips, EPA Region 5, Chicago, IL
Randy Revetta, EPA Center for Environmental Research Information, Cincinnati, OH
Don Roberts, EPA Region 5, Chicago, IL
Sue Schock, EPA Center for Environmental Research Information, Cincinnati, OH
Peter Swenson, EPA Region 5, Chicago, IL

**Editorial Review and Document Production**

Heidi Schultz, Eastern Research Group, Inc., Lexington, MA, directed the editorial review and production of this document.

**Technical Direction and Coordination**

Daniel Murray, EPA Office of Research and Development, Center for Environmental Research Information, Cincinnati, OH, coordinated the preparation of this document and provided technical direction throughout its development.

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## *Introduction*

### Background

As stormwater and snowmelt flow across the urban landscape, countless contaminants are carried into our rivers, lakes, and estuaries. The effects of these contaminant discharges on the environment can be severe. Water quality and sediment characteristics can be degraded, threatening the biological integrity of our urban water bodies. In addition to urban runoff quality, the quantity of urban stormwater and snowmelt that reaches urban streams can cause severe physical harm to sensitive ecosystems, including those well beyond urbanized areas.

The proper management of urban watersheds is a challenging and complex task. As urban watersheds are developed, they produce a site-specific mix of pollutants that can adversely affect water and sediment quality. Also, with increased urbanization comes increased impermeability, resulting in higher stormwater flows to streams that can cause streambed and streambank erosion. Urban runoff management is particularly difficult because government jurisdictions rarely coincide with watershed boundaries. So, to overcome these institutional obstacles and implement effective urban watershed management programs, comprehensive and coordinated management strategies are needed.

The National Conference on Urban Runoff Management was held in Chicago, Illinois, from March 30 to April 2, 1993. The purpose of this conference was to bring together national experts in the field of urban watershed management to discuss and share ideas and approaches for effective urban watershed management. This 4-day conference addressed a wide variety of institutional and technical issues, from watershed planning and public information programs to the design and application of best management practices.

### Purpose

The purpose of this seminar publication is to make available to a much wider audience the valuable information presented at the National Conference on Urban Runoff Management. This publication comprises 53 papers that were presented at the conference. The papers address a broad spectrum of programmatic and technical topics relating to urban watershed management, including:

- Watershed planning
- Stormwater management programs
- Regulatory issues
- Monitoring, modeling, and environmental assessment
- Design and application of best management practices and controls
- Education and information programs

The papers in this publication represent the collective knowledge and experience of many talented individuals who have developed and are implementing and supporting watershed management programs at the federal, state, county, and local level. As a result, this document will be a valuable resource to regulators, watershed management program personnel, and others interested in developing and implementing a successful urban watershed management program.

# *Watershed Planning and Program Integration*

**Eric H. Livingston**
**Florida Department of Environmental Regulation, Tallahassee, Florida**

## Abstract

Since passage of the Clean Water Act, federal, state, and local governments together with the private sector have spent billions of dollars attempting to meet the act's goals of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. While great progress has been made, especially with respect to reducing traditional point sources of pollution, we are faced with a much more complex and difficult challenge: reducing the pollution associated with our everyday activities. Facing the environmental challenges presented by nonpoint sources and stormwater discharges requires a more comprehensive and integrated approach, especially if we are to maximize the environmental benefits in a cost-effective manner. This approach is known as watershed management—the integration, on a watershed basis, of the management of land resources, water resources, social-cultural resources, financial resources, and infrastructure. Implementation of this approach requires a cooperative Watershed Management Team effort involving all levels of government, the private sector, and each citizen.

Besides addressing the need for watershed management, this paper discusses briefly the many components of a comprehensive watershed management program. Key program elements include growth management, land preservation/purchase, wetlands/floodplains protection, erosion and sediment control, stormwater management, wastewater management, watershed prioritization and targeting, inspections and maintenance, research, public education, and dedicated funding sources. Other papers in this publication review the evolution of Florida's watershed management program, with emphasis on successes and failures together with recommendations to improve the environmental effectiveness of the program (e.g., "The Evolution of Florida's Stormwater/Watershed Management Program").

## Introduction

When land within a watershed is changed from its natural state to agricultural land and then to urban land, many complex interconnected changes occur to the natural systems within the watershed. These changes can and do have profound effects on the health of these systems as well as their inhabitants. As Earl Shaver describes in his paper, one of the greatest changes is the alteration of the watershed's hydrology, especially the infiltrative capacity of the land. Additionally, the everyday activities of humans within the watershed add many potential environmental contaminants to the watershed that can be easily transported by precipitation and runoff.

Managing stormwater and nonpoint sources of pollution presents many complex challenges to the water resources manager that are somewhat unique and quite different from those encountered when managing traditional point sources of pollution. These challenges include:

- Integrating land-use management, because change in land use creates the stormwater problems.
- Educating the public about how everyday activities contribute to the stormwater/nonpoint source problem and how they must be part of the solution.
- Developing a management framework that is based on the fact that "we all live downstream" and that stormwater flows are not constrained by political boundary lines.
- Obtaining the cooperation and coordination of neighboring political entities that exist within a watershed.
- Not only managing stormwater from new development but retrofitting existing "drainage systems" that were built solely to convey runoff away from developed lands to the nearest water body as quickly as possible.

Secondly, constraints imposed by current stormwater treatment technology, such as treatment efficiency, land needs, and maintenance needs, and by the costs of assessing and solving existing stormwater/nonpoint source pollution problems call for a cooperative and regional framework. Additionally, the proliferation of federal programs and requirements imposed by federal legislation, such as the Federal Clean Water Act and the Coastal Zone Management Act, has caused fragmentation of efforts and created program "turf wars" and even conflicts between programs within the U.S. Environmental Protection Agency (EPA). Other federal programs such as the National Flood Insurance Program, the Section 205 flood control program, and even agricultural crop subsidy programs directly conflict with achieving the goals set forth in various environmental laws and programs. Finally, current environmental management approaches rely on regulatory efforts that attempt to compensate for adverse effects caused by land alteration activities on a particular site. Implementing a watershed management approach helps to overcome all of these challenges and, just as importantly, allows inclusion of planning efforts that can prevent problems. This allows for more extensive use of less expensive nonstructural management practices.

## Watershed Management

"Watershed management" is a flexible framework for integrating the management of all resources (land, biological, water, infrastructure, human, economic) within a watershed. Basically, it is the managing of human activities so as to cause the least disruption to natural systems and native flora and fauna. With respect to the management of stormwater and nonpoint sources, the crucial factor is the integration of the management of land use, water/stormwater, and infrastructure. Watershed management has numerous facets, including planning, education, regulation, monitoring, and enforcement, that are performed on a watershed basis.

The watershed management approach discussed in this paper must be flexible. The size of the watershed to be managed can be very large (a river basin) or very small (a subbasin). Selection of watershed size depends on many factors, including ecological systems in the watershed, ground-water hydrologic influences, the type and scope of resource management problems and goals, and the level of resources available. Additionally, the institutional framework for watershed management will vary greatly depending on the legal framework that has been established in state law and local ordinances.

### *Advantages of Watershed Management*

As discussed above, solving our nation's stormwater/nonpoint source problems, especially retrofitting existing "drainage systems" to reduce the pollutant loads they discharge to receiving waters, presents many complex challenges. Correcting these problems will be extremely expensive and technically difficult, and will take a long time. Accordingly, we need to re-evaluate our current approach to stormwater management to shift the emphasis towards more comprehensive, prevention-oriented strategies such as watershed management.

The following comparison illustrates the differences between the usual piecemeal approach to stormwater management and a comprehensive watershed approach (1):

- The usual approach: For existing urban development, the usual approach is to address local stormwater problems without evaluating the potential for the runoff control measure to cause adverse effects in downstream areas. In the case of new urban development, stormwater management responsibilities would be delegated to local land developers, and each would be responsible for constructing stormwater management facilities on the development site to maintain postdevelopment peak discharge rate, volume, and pollutant loads from the site at predevelopment levels. There would be little or no consideration of the cumulative effects of the developments with their individual stormwater systems on either the local government stormwater infrastructure or the downstream lands and waters.
- The watershed approach: This option involves developing a comprehensive watershed plan, known as the "master plan," to identify the most appropriate control measures and the optimal locations to control watershedwide activities. The watershed approach typically involves combinations of the following:
  - Reviewing the watershed and its characteristics to assess problems and potential solutions.
  - Strategically locating a single stormwater management facility (a regional system) to control postdevelopment runoff from several projects within a basin (or from a fully developed basin or subbasin).
  - Providing stormwater conveyance improvements where necessary upstream from the regional facility.
  - Employing nonstructural measures throughout the watershed, such as acquisition of floodplains, wetlands, and natural stormwater depressional storage areas; soundly planned land use; limitations on the amount of imperviousness; grassed swales rather than storm sewers; and roof runoff direction to pervious areas.

While the usual approach to urban stormwater management is relatively easy to administer, it offers several disadvantages. There is a greater risk of negative effects, particularly in watersheds that cover several jurisdictions. Insignificant flood protection benefits result from emphasis on the effects of minor localized flooding. Ineffective runoff control throughout the watershed is caused by the failure to evaluate locational differences in the benefits of stormwater management facilities. Relatively high local costs for facility maintenance are incurred, as are unnecessary costs associated with the use of small-scale structural solutions rather than large-scale nonstructural solutions, which typically are much cheaper.

Included among the possible negative effects of this piecemeal approach to stormwater management are the following:

- It may only partially solve the major flooding problem(s).
- It may solve flooding problems in the upstream jurisdiction but create flooding problems in downstream jurisdictions.
- Randomly located detention basins may actually increase downstream peak flows.
- Maintenance needs and costs associated with numerous onsite runoff controls are very high.
- Significant capital and operation/maintenance expenditures may be wasted.
- The costs of remedial structural solutions likely will be much greater than the cost of a proper management program.

The watershed master planning approach offers significant advantages over the piecemeal approach. It promises reductions in capital and operation/maintenance costs and reductions in the risk of downstream flooding and erosion, particularly in multijurisdictional watersheds. It offers better opportunities to manage existing stormwater problems and the ability to consider and use nonstructural controls. Other benefits include increased opportunities for recreational uses of stormwater controls, potential contributions to local land-use planning, enhanced opportunities for stormwater reuse, and popularity among land developers.

There are some disadvantages to the watershed approach:

- In advance, local governments must conduct studies to locate and develop preliminary designs for regional stormwater management facilities.
- Local governments must develop and adhere to a future land-use plan so that the regional facility is properly designed to capture runoff from the planned amount of development and impervious surfaces.
- Local governments must finance, design, and construct the regional stormwater management facilities before most development occurs and provide for reimbursement by developers over a buildout period that can last many years.
- In some cases, local governments may have to conduct extraordinary maintenance activities for regional facilities that the public feels are primarily recreational facilities that merit protection for water quality.

Another advantage of watershed management is that the resource management goals can be more resource oriented. Prevention practices and programs to protect natural systems and beneficial uses of our water bodies can be stressed. These typically are more cost effective than trying to restore natural systems after they have been adversely affected by human activities that occur within a watershed.

*Watershed management allows coordination of infrastructure improvements with point and nonpoint source management programs and, most importantly, provides a vital link between land use and water resources management.*

## Watershed Management Framework

There is no single approach or institutional framework for establishing a watershed management program. While establishing a watershed management institutional and legal framework would be easiest if we could start with a clean slate, we cannot. There is an existing legal framework in each state, county, and city. These may differ greatly. In some states, there will be a long list of existing laws, rules, and programs that have been set up to respond to earlier state needs. In other states, there will be very few laws, rules, and programs that can form a foundation for establishing watershed management programs. Therefore, one of the keys to opening the watershed management door is flexibility. In some cases, the focus will be on enacting new laws. In other cases, the emphasis will be on revising existing laws (ordinances) to better integrate and coordinate programs and objectives.

Another key to establishing a watershed management framework is patience. Getting state laws or local ordinances enacted or modified is not an easy process. A long-term game plan must be developed and pursued with diligence. Each component of a watershed management program has its own controversies, guaranteeing that public debate will be vociferous on many issues. Therefore, priorities must be established. Typically, priority setting depends on state resource problems and needs, public sentiment, and the degree to which an issue becomes “sexy,” thereby receiving coverage by the news media. In many cases, it may take several years to get a particular piece of legislation passed or revised.

To succeed, education of elected officials, state agency managers, and the public must be a priority. Public participation and support are essential in building a consensus. Many of the issues that watershed management programs address are complex and not easily demonstrated. Managers of stormwater and other nonpoint sources of pollution, unlike the managers of traditional point sources of pollution, cannot point to pipes that continuously discharge effluents. Therefore, promoters of watershed management programs must use multimedia presentations to not only educate but also to entertain. You must sell the need for watershed management!

Another key to success is to take advantage of any opportunities that arise. Unfortunately, these opportunities often occur after a natural disaster that results in the loss of property or lives. After Hurricanes Frederick and Andrew struck South Carolina and South Florida, respectively, considerable public debate arose about building codes, land uses, and development within sensitive and susceptible coastal area—whether to allow rebuilding in these areas and whether public programs such as the National Flood Insurance Program should subsidize development in such areas. These debates, especially of the costs and benefits, can be used to help build support for growth management and land acquisition programs. Furthermore, flooding (and in a few locales, water quality problems) can be used to break the "hydro-illogical cycle" and gain support for stormwater management programs and local stormwater utilities.

Finally, in building a watershed management framework, one must establish clear goals for the overall program. Some important goals include:

- Providing opportunities for preventive nonstructural controls in addition to structural controls that can help to mitigate the impacts of human activities within a watershed.
- Establishing clearly defined, holistic natural resource management goals.
- Setting priorities, both in terms of a long-term legislative agenda and by targeting watersheds.
- Encouraging public participation so that everyone "buys in" and feels that they are part of the solution.
- Integrating all available tools and resources into a coordinated, cost-effective, cooperative approach.
- Finding dedicated funding sources outside the main funding stream (also known as "general revenues") so that the watershed management programs do not compete with law enforcement, education, or other high-priority societal needs.

In developing, selling, establishing, and implementing a watershed management framework and associated programs, it is very important to keep in mind "the big Cs of watershed management" (2):

- *Comprehensive* management of people, land use, natural resources, water resources, and infrastructure throughout a watershed.
- *Continuity* of stormwater/watershed management programs over a long period, which is required to correct existing problems and prevent future ones.
- *Cooperation* between federal, state, and local governments; cities and counties; public and private sectors; and all citizens.
- *Communication* to educate ourselves and elected officials about how we are all part of the problem and how we can and must be part of the solution.
- *Coordination* of stormwater retrofitting to reduce pollutant loading and of other natural systems restoration activities with other proposed infrastructure improvements (e.g., road projects) or development/redevelopment projects to maximize benefits and cost-effectiveness.
- *Creativity* in best management practice technology, in funding sources, and in our approach to solving these complex, costly problems.
- *Consistency* in implementing laws, rules, and programs nationally and statewide to assure equity and fairness for everyone.
- *Cash* in large amounts and over a long period to correct existing problems and prevent future ones.
- *Commitment* to solving our current problems and preventing future ones so that we can ensure that our children have a bright future ("Just Say No To Stormwater Pollution").

## Watershed Management Program Components

Watershed management involves the integration of management programs addressing the many differing human activities that occur within a watershed. This section discusses briefly many different components or programs that typically are considered a part of watershed management. The following list and discussion of programs is not all inclusive. Other programs addressing specific state or regional needs have been implemented around the country. In developing or implementing programs, it is important to take advantage of information and technology transfer clearinghouses and to communicate with people in other states, cities, and counties who have implemented similar programs.

Each of the various watershed management programs includes common aspects such as planning, holistic goals, science/technical support, implementation (usually with both regulatory and nonregulatory approaches), and extensive public participation. Public participation is needed in all aspects of the program: planning, rule development and adoption, permitting, and inspection/enforcement. Programs must also address how to obtain adequate funding and staffing; how to train staff and the public, especially the regulated community; how to ensure inspection and compliance; and how to ensure long-term operation and maintenance of structural controls. Finally, programs must be evaluated regularly to optimize their environmental effectiveness, cost-effectiveness, and efficiency in providing service. This requires a commitment to monitoring programs that can actually ascertain if the program's goals are being met.

Typically, these programs are implemented following enactment of a state law that requires a state agency to set up a program to address a specific concern. Program implementation via legislative mandate usually helps to ensure that a program has adequate legal authority and staffing/funding support. Some of the programs discussed can and have been established by the passage of a rule by a state agency using its general legislative powers, for example, programs for public education, pollution prevention, monitoring, and prioritizing target watersheds. Given the current scientific data on the pollutants found in stormwater, erosion and sediment control and even stormwater treatment programs can be established using general water pollution control authorities. These programs are very staff/resource intensive, however, requiring legislative approval of budget requests at a minimum.

Common watershed management programs include both planning and regulation. It is important to understand the difference between comprehensive planning and permitting. Both are needed to effectively manage growth and protect the quality of our environment and our citizens' quality of life:

- *Comprehensive planning* allows a community to make decisions about how and where growth will occur in the future. Comprehensive planning asks, is this the right location, is this the right time, and is this the right intensity for the proposed use of the land? Comprehensive planning seeks to prevent problems (social, economic, environmental) before development occurs.

- *Permitting,* on the other hand, asks only, how can we do the best job with this development on this particular site? Permitting is site-specific and seeks only to mitigate the impacts of the land-use decision. There always are inherent limitations in any regulatory program that comprehensive planning can help to overcome. Principal among these limitations is the fact that permitting is piecemeal and does not consider cumulative effects. Therefore, regulation and permitting cannot substitute for planning.

Watershed planning and management programs must include two equal components: the land planning framework and the water planning framework. An example of the hierarchial relationship of these planning frameworks is shown in Table 1.

**Table 1. The Land Planning Framework Versus the Water Planning Framework**

| Land Planning | Water Planning |
|---|---|
| Land development regulations | Water management regulations |
| Local compliance plans | State water management plans |
| Regional policy plans | State water policy |
| State comprehensive plan | State comprehensive plan |

Following is a discussion of many of the program components that typically are part of a watershed management framework. These can be divided into three categories:

- Land planning and management
- Water planning and management
- General resources planning and management

## *Land Planning and Management Program Components*

Land planning and management programs often are called growth management programs. It is important to understand the clear distinctions between growth management, comprehensive planning, and land/environmental regulation:

- *Growth management* looks at broad issues and at the interrelationship of systems—natural systems, infrastructure, land use, and people. It attempts to assess how well we have been providing for the needs of our citizens in the past and, when new people move here, to determine what their needs are and how they will be provided. Growth management encompasses comprehensive planning, natural resource management, public facilities planning, housing, recreation, economic development, and intergovernmental coordination.

- *Comprehensive planning* is a governmental process for inventorying resources, establishing priorities, establishing a vision of where a community wants to go, and determining how to get there. It is a systematic way of looking at the different components of a community, county, region, and state.

- *Regulations* are the specific controls applied to different types of development activities to regulate and minimize their negative impacts. Typically, regulations are administered by all levels of government, federal, state, and local. At the local level, land development regulations are the ordinances that implement the local comprehensive plan.

## State Comprehensive Plan

A state comprehensive plan serves as the base of both the land and water planning pyramids. A State Comprehensive Planning Act would establish goals and policies for each of the plan's various elements and require the state land planning agency to prepare a general state comprehensive plan. Elements in a state comprehensive plan usually include water resources, natural systems, air quality, coastal and marine resources, land and wildlife resources, waste management, public facilities (infrastructure), transportation, mining, agriculture, education, and economic development. If the state's land planning framework includes "regional planning councils" or "regional council of governments," those agencies would be responsible for developing a regional plan. Both the state and regional plans would have to be consistent with the goals and policies set forth in the state comprehensive planning act. These goals and policies, set by the legislature, are to provide guidance to state, regional, and local governments in developing and implementing programs, rules, or ordinances. Consistency must occur from the base of the planning pyramid all the way to its apex. To help ensure consistency and to integrate agency implementation programs with the law's goals and policies, this law can require the preparation of state agency functional plans. These plans can form the basis for agency budget requests, which must be related to the state comprehensive plan's goals and policies.

## Growth Management and Land Development Regulation

The Local Government Comprehensive Planning Act (LGCPA), often referred to as the growth management act, establishes the key piece of the natural resources jigsaw puzzle: the direct connection between land-use management and water/natural systems management. Eight states (Oregon, Florida, New Jersey, Maine, Vermont, Rhode Island, Georgia, Washington) have implemented state growth management programs (3). While these programs have elements in common, each state has different implementation requirements. Some states "require" while other states "recommend" local plans, consistency, compliance, etc. An LGCPA should at least address the following components, which are common to each of the eight existing state growth management programs:

- Legislative authority and intent.
- Local comprehensive plans: Required? Voluntary? Schedule? Planning period? Required elements? Minimum requirements?
- Plan implementation: Required? Site planning? Land development regulations?
- Consistency with state goals/policies: Required? Monitoring? Enforcement?
- State review and approval: Required? Which agencies? Administrative process?
- Compliance: Monitoring? Incentives? Disincentives? Citizen enforcement?
- Limitations on the number and type of comp plan amendments: Frequency? Process?
- Regular plan updates and implementation appraisals: Required? Frequency?

## Wetlands and Floodplain Protection

Wetlands and floodplains are the "bladder" and "kidneys" of a watershed. They provide a wide range of irreplaceable services at no cost, including maintenance and improvement of water quality; floodwater conveyance and storage; shoreline stabilization; water recharge and supply; sediment control; aquatic productivity; spawning and nursery grounds; habitat for shellfish, fish, waterfowl, endangered species and other wildlife; and open space and recreation. Unfortunately, we have not in the past appreciated these benefits. Instead, we looked on these areas as unproductive, snake-infested mosquito havens with no socially accepted redeeming value. Consequently, only about 40 percent of our nation's original 215 million acres of wetlands remain, largely the result of the conversion of wetlands and floodplains to agricultural lands.

Although Section 404 of the Federal Clean Water Act establishes a wetlands program, its effectiveness in maintaining, protecting, and restoring our nation's wetlands is highly questionable. Not only are nationwide general permits to conduct activities in wetlands relatively easy to obtain, but agricultural and silvicultural activities are largely exempt. Another problem hindering the environmental effectiveness of this federal program is a lack of national consistency. Furthermore, other federal programs (e.g., Section 205 of the 1948 Flood Control Act, National Flood Insurance Program) directly conflict with wetland and water quality protection efforts by promoting alteration and development of these sensitive lands.

A state wetlands protection act can be an important addition to a state's watershed management arsenal to either fill in the gaps of the federal program or to expand the protection of wetlands and floodplains. In developing and implementing a state wetland protection program, it is important to integrate, not duplicate, existing federal programs. Because the current federal wetlands permitting program is administered by the Army Corps of Engineers and EPA, typically the state water quality/environmental management agency is the implementing agency at the state level. Frequently, the "wetlands protection act" is simply a new section within a state's existing environmental laws.

Components that need to be addressed by a state wetlands/floodplain protection act include:

- Defining "wetland." A wetland should be defined by three characteristics: the elevation and duration of flooding, the presence of certain wetland-specific plants, and hydric soil conditions. The law should clearly state that wetlands are considered to be "waters" just like a river, lake, or estuary.
- Establishing a standard method to delineate wetlands. Wetlands represent the transitional edge between waters and uplands. Determining where a wetland ends and the upland begins is neither an easy nor an uncontroversial undertaking. Wetland scientists should be allowed to establish combinations of hydrologic, vegetation, and soil indicators and a process by which to "draw the wetland line."
- Requiring consistant statewide application of the wetland definition and wetland jurisdictional delineation method by all levels of government.
- Establishing wetland protection/management goals and policies that can set the basis for wetland regulations and permitting criteria.
- Creating goals and policies that foster more cost-effective pollution prevention approaches by stressing wetland avoidance rather than mitigation.
- Requiring or encouraging regional mitigation banks rather than onsite mitigation.
- Establishing a fair permitting process that ensures public participation, equity, an appeals process, and decisions based on scientific/technical merit.
- Allowing, with strict pretreatment requirements, the incorporation of certain wetlands into domestic wastewater and stormwater management/reuse systems, provided that the ecological characteristics of the wetland are protected, restored, or enhanced.
- Requiring the annual tracking of wetland losses and mitigation efforts, successes, and failures.
- Providing for assumption, by the state, of the federal Section 404 wetlands program.

### State and Local Land Preservation and Acquisition

Regulating and restricting the use of private property are very controversial. The U.S. Supreme Court has ruled several times, however, that state and local governments have the legal authority to do so. In fact, it is the responsibility of government to ensure the health, safety, and welfare of the public. Restricting what can and cannot be done on a particular piece of property helps to maintain property values and to prevent contamination of air, land, water, and human resources. Care must be taken, however, to avoid the "taking of property." One way to help ensure that this goal is met and that extremely crucial or sensitive lands within a watershed are preserved is to implement land acquisition programs.

The federal government has implemented several types of land acquisition programs that have helped to preserve sensitive lands, protect vital wildlife habitats, and establish recreational lands, such as our national parks and national wildlife refuges. Federal budget problems and intense competition for the limited federal land acquisition funds, however, makes it difficult to gain these monies to obtain properties, especially those that do not have national or at least regional significance. Additionally, federal funding programs generally require matching funds from state and/or local governments. Therefore, the establishment of state and local land acquisition programs can greatly increase the ability to purchase and protect sensitive lands and, equally importantly, to capture limited federal funds.

Establishing state or local land acquisition programs requires extensive citizen participation and support. You will be asking the public to tax themselves to raise money to purchase lands, preserve them, and provide recreational opportunities. You must "sell" the program. Catchy phrases and acronyms are helpful. Citizens must see that they or their children will benefit and that the funds will be spent wisely and cost-effectively. Land acquisition programs must avoid conflicts of interest and be administered with great integrity and openness.

A state and local land preservation and acquisition act should contain the following components and considerations:

- Clearly defined program goals and policies. These will form the foundation for determining what types of properties will be purchased and how purchasing priorities will be established. The program's goals and policies should advocate the preservation and restoration of lands that contribute nonstructural environmental benefits. Additional resource management factors that should be considered in purchasing lands include open space and recreational and wildlife benefits.
- Integrated and coordinated federal, state, local, and private land preservation and acquisition programs. This will maximize the ability to leverage funds from various sources. Establishing interconnected wildlife corridors and greenways should be a priority.
- Extensive participation by citizens, private conservation groups, and state and local governments to establish program regulations, administrative procedures, and, most importantly, land-buying priorities.
- The long-term ownership and active land management of the property once it is purchased. Which agency

will be in charge, an environmental agency? A parks and recreation agency? A fisheries or wildlife agency? A private organization (i.e., Nature Conservancy, Trust for Public Land)? Does a land management plan need to be developed? How will land management be funded?

- Dedicated funding sources. Purchasing large quantities of land and then managing the land, especially with public access and use, requires significant funds over a long period. To obtain sufficient funds, it may be desirable for a state or local government to use its ability to sell bonds. Bonds can raise large amounts of money at one time, which can then be paid off like a mortgage. However, that requires having a source of funds that is stable and predictable over the life of the bond. Fees on real estate transactions (e.g., documentary stamps) and local option sales taxes have been used extensively around the country for this purpose.

### *Water Resources Planning and Management Programs*

In general, the United States is blessed with an abundance of clean water resources. Water generally is available whenever we want it, in whatever quantity we desire and at a very low cost. Consequently, less attention and emphasis have been placed on water resources planning and management, especially from a holistic approach. In the past, water planning and management programs were implemented usually to address a crisis that had arisen. The continuing growth of our nation's population, however, continues to exert ever-growing demands on our vulnerable and limited water resources. Additionally, the need to begin managing unconventional pollution sources such as stormwater and other nonpoint sources requires a re-evaluation of the way we manage water. Accordingly, water resource planning and management programs are receiving increased attention and evaluation.

Within this subcategory of watershed management programs, we include water quantity and quality programs for the protection and management of surface and ground waters, as well as general environmental protection programs. All of these programs usually include both pollution prevention aspects and pollution treatment aspects.

#### Environmental Protection

Most states have enacted some type of state environmental protection act, typically to control traditional point sources of pollution. Generally, these laws are patterned somewhat after the federal Clean Water Act. These laws get revised frequently as either a new state environmental crisis or concern arises or the Clean Water Act gets amended by Congress. This law is an excellent example of how, over years, an existing law is revised to establish or refine existing or new environmental requirements or programs.

While state environmental protection laws around the country include many common and similar environmental requirements and mandates, there is also considerable variation among states. A major reason for this is that different states approach the same problem differently. For example, some states enact separate erosion and sediment control acts and stormwater management acts. Other states combine these two very important watershed management components. In some states, the law governing the siting and use of onsite wastewater disposal systems is found within a state's general health code law, while in other states it is found within the environmental law. These three watershed management components will be discussed as separate topics even though their legislative authority often is integrated into a state's environmental laws.

State environmental protection laws generally contain such components and considerations as:

- Establishment of the state environmental agency, along with its legal authority and powers and responsibilities.
- Establishment of an "environmental regulation commission," generally composed of citizens appointed by a political body (i.e., governor), which usually holds public workshops and adopts the state's environmental regulations and standards.
- Permitting evaluation criteria, permit fees, and administrative procedures, which typically include a legal, administrative hearing process to appeal permitting decisions.
- Programs, with adequate legal authority/direction and resources (staffing and funding), to address general environmental protection and management of air, land, and water resources (surface and ground water).
- Programs, with adequate legal authority/direction and resources, to minimize the impacts of specific pollution sources such as wastewater and industrial discharges, solid wastes, hazardous wastes, and toxic wastes.
- Pollution prevention programs such as "Amnesty Day," which allows citizens to safely dispose of hazardous or toxic household wastes; used oil recycling centers; waste reduction and assistance programs for industry; "Adopt a Road (Stream, Lake, Bay, Shoreline)" programs; recycling; and "Farmstead Assistance" ("Farm*A*Syst") programs.
- Programs to restore environmentally damaged lands and waters, especially critical areas such as wetlands, floodplains, steep slopes, and eroding lands.
- Programs to monitor the health of the environment and to assess the effectiveness of watershed man-

agement programs. Monitoring programs need to include sampling of the water column, sediment, and biological community. They need to be able to provide information concerning long-term trends in environmental health, as well as the status of the health of selected water bodies or natural systems.

### Water Resources Planning and Management

Many states have enacted a water resources act that is distinct and separate from the state environmental protection act, perhaps because the planning and management of water resources is essential to the continued survival of life on our planet and because water is a major determinant of economic development and quality of life. Water resources planning and management must include consideration of both water quantity (water supply, water allocation, flooding) and water quality. A state water resources act needs to be fully integrated with the state environmental protection act. It must ensure that implementation of programs by both the state environmental protection agency and state/regional water resources agency is coordinated, consistent, and complimentary.

A state water resources act creates the framework for water resources planning and management programs to be undertaken by state, regional, and local governments. Using the goals and policies of the state comprehensive planning act, the environmental regulation commission adopts a regulation known as its state water policy. This rule contains general policy statements addressing the myriad water resource topics, such as water supply and conservation, surface water preservation and management, and natural systems preservation and management. It provides guidance for the implementation of all water resource programs and regulations, whether by a state, regional, or local entity. The act could establish regional "water(shed) management districts" which are set up on the basis of watershed boundaries. The districts would conduct regional watershed planning, help coordinate water management efforts undertaken by local agencies to ensure that watershedwide goals are met cooperatively, and operate regulatory and research programs.

A state water resources act should include such program components and considerations as:

- Establishing water(shed) management districts to administer special regional (watershed) water planning and management programs. These districts should provide statutory authorities and be given broad powers to protect, manage, and restore surface- and ground-water resources.
- Setting the institutional relationships between the state environmental agency, regional water management districts, and local governments. Strong oversight of programs, especially regulatory ones, delegated downwards for implementation is essential to ensure program consistency.
- Developing a state water policy to provide guidance for the implementation of all water programs and regulations in the state, which should be adopted as a rule, preferably as part of the state's environmental regulation code. The state water policy must be based on and consistent with the goals and policies in the state planning act. State, regional, and local water regulations and programs must be consistent with the state water policy. Ideally, goals and policies in a local comprehensive plan should also be consistent with the policy.
- Providing the districts with dedicated sources of revenue to ensure long-term, adequate funding of all necessary water resource management programs. Sources used in parts of the country include *ad valorem* assessments (property taxes), fees on water use, permitting fees, and special assessments.

### Supplemental Surface Water and Environmental Protection Programs

There are several watershed management component programs that may be established within one of the above two statutes or which may be established in statute separately.

**Erosion and Sediment Control Act/Program.** Land disturbing activities are among the largest source of sediments and particle-borne pollutants. Preventing erosion and minimizing and capturing sediments, especially from construction sites, are essential parts of any watershed management framework. Since 1972, over 20 states have enacted erosion and sediment control laws and programs.

Establishment of an erosion prevention and sediment control law or program should include the following components and considerations:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the implementing state and/or regional or local agencies.
- Assurance that publicly funded projects, especially highways, must comply with all program requirements, and an encouragement for these projects to serve as models.
- Determination of whether utility construction, agricultural, and forestry projects are to be included in the program.
- Agency responsibilities and relationships. Typically, implementation of an erosion and sediment control program involves a state agency and a regional/local agency such as a soil and water conservation district

or a local government. Delegation of the program from the state to the local agency must involve close oversight to ensure consistency.

- Adequate staffing and other resources to conduct research on the effectiveness of control measures, develop scientifically sound rules, and conduct training and education programs for plan reviewers, inspectors, developers, engineers, and site contractors. A state training and certification program for plan reviewers, inspectors, and contractors is highly recommended because it is very unlikely that public agencies will ever obtain sufficient staffing to conduct inspections of construction sites on a regular basis.
- Mutual integration of the state erosion and sediment program, the state stormwater management program, and the new federal National Pollutant Discharge Elimination System (NPDES) Stormwater Permitting Program.

**Stormwater Management Act/Program.** Most states have implemented some type of stormwater "drainage" program to ensure that their citizens and their properties are protected from flooding. In some states, special "drainage districts" or "drain commissions" have been established at a regional or local level. Today, however, we know that stormwater is also one of the major sources of pollutant loadings to our nation's rivers, lakes, and estuaries. Stormwater management is evolving slowly from its "drainage" focus to a much more comprehensive, multiple-objective program that addresses stormwater quality and quantity. Stormwater programs must attempt to prevent or minimize stormwater problems associated with new land-use activities but must also develop programs to reduce the pollutant loading discharged from older "drainage systems." This latter objective is extremely difficult and expensive to address. Watershed management approaches are essential. Typically, a state stormwater management program begins by addressing the problems associated with new land uses and then evolves into a more comprehensive, watershed-based program to address the retrofitting of older stormwater systems.

Components and considerations that need to be addressed by a state stormwater management act/program include:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the implementing state and/or regional or local agencies.
- Assurance that publicly funded projects, especially highways, comply with all program requirements, and an encouragement for these projects to serve as models.
- Agency responsibilities and relationships. Typically, implementation of a stormwater management program involves a state agency and a regional/local agency such as a water(shed) management district, soil and water conservation district, or a local government. Delegation of the program from the state to the local agency must involve close oversight to ensure consistency.
- General goals and minimal treatment performance standards (on which best management practice design criteria will be based) based on the state water policy, and a biological or resource based performance standard for reducing the pollutant loading from existing drainage systems.
- Adequate staffing for planning, coordinating, permitting, and enforcement, and resources to conduct research on the effectiveness of control measures; to develop scientifically sound rules; and to conduct training and education programs for plan reviewers, inspectors, developers, engineers, and site contractors.
- A state training and certification program for plan reviewers, inspectors, and contractors. This is highly recommended, because it is very unlikely that public agencies will ever obtain sufficient staffing to conduct inspections of stormwater systems either during construction or afterwards on a regular basis. These programs can be integrated with similar erosion and sediment control programs.
- Integration of the state stormwater management program with the state erosion and sediment control program and with the new federal NPDES Stormwater Permitting Program.
- A mechanism, such as stormwater operating permits, to ensure that stormwater management systems are inspected at least annually to determine maintenance needs and that systems are maintained and operated properly. Ideally, this system is implemented by a local stormwater utility which provides the owner of a properly maintained and operated stormwater system with a stormwater utility fee credit as an economic incentive.
- Statutory authority for the establishment of dedicated funding sources for stormwater management programs at both the state and local level. At the state level, small fees on concrete, asphalt, fertilizer, or pesticides might be considered. At the local level, stormwater utilities are widely used around the country with great success.

**Watershed Prioritization and Targeting Act/Program.** The ever-growing number of water resources problems along with the financial constraints faced by all levels of government strongly suggest a need for the establishment of watershed prioritization and targeting programs. Many states, often as part of the implementation of stormwater/nonpoint source management programs, have set up such programs (4, 5). Considerations and components of a state watershed prioritization and targeting act/program include:

- Clearly identifying which state, regional, and local agencies will be involved in establishing priority watersheds. Public participation is essential to ensure the cooperation and "buy in" of citizens around the state and within the targeted watershed. Cooperation and joint ventures with private land conservation groups need to be encouraged.
- Providing guidance on what factors will be considered in the prioritization process. These may include requirements such as water bodies being of statewide or regional significance or of a certain level of degradation; the level of local government and citizen support, especially by those land owners that will need to install management practices; and the availability of local matching funds.
- Providing a legal mechanism for the adoption of the "priority list" by the appropriate state, regional, or local agency. Ensuring that the list is reviewed on a regular basis and updated or refined as needed.
- Providing a dedicated source of funds (state, regional, local) to develop and implement a watershed management plan within a realistic time schedule.

**Onsite Wastewater Management Act/Program.** The nation's rapid population growth and the accompanying move to the suburbs and even more rural areas has led to a tremendous proliferation of the use of onsite wastewater disposal systems (OSDSs). Often considered an inexpensive alternative to centralized wastewater collection and treatment systems, OSDSs can cause or contribute to health and environmental resource problems which are difficult and very expensive to solve. Like many areas of nonpoint source management, OSDS programs need to stress prevention but also be able to correct problems related to the past use and misuse of these systems. Traditionally, state health departments rather than state environmental or water resources agencies have administered OSDS programs. It is increasingly evident, however, that OSDSs are a major contributor to impairment of aquatic systems.

A state onsite wastewater management act/program should include the following components and considerations:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the state, regional, or local entities involved in the implementation of the program.
- Goals and performance standards that not only address traditional health concerns but that also require consideration of the potential environmental effects of OSDSs.
- The adoption of OSDS regulations that govern the types of OSDS systems (e.g., drainfields, mound systems, aerobic units), the siting of systems (e.g., watertable elevation, soil types, setbacks from wetlands/waters), the design and performance of OSDS (e.g., secondary treatment? nitrates ≤10 mg/L?), determination of whether surface discharges will be allowed and under what conditions, inspections during construction and throughout the use of the system, and maintenance.
- Regular inspection (every 2 to 3 years) and maintenance (e.g., pumpout, drainfield) to help ensure that OSDSs continue to function properly. The establishment of OSDS management districts, which have defined service areas, funding sources, and legal authority, is one mechanism that can be used. Another method of ensuring that OSDSs continue to function properly is to require inspections and upgrading/maintenance of systems whenever a property is sold.

### *General Resources Planning and Management Programs*

One of the challenges of implementing watershed management frameworks and programs is their complex, interwoven nature. Many aspects of watershed management transcend the simple classification scheme outlined at the beginning of this section. These include the need for broad-based natural resource management programs and for environmental education programs, especially those integrated into the curriculum of the K–12 education system. In many states, separate agencies have been established that have responsibility for the management of land, fish and wildlife, agriculture, mining, and parks and recreation. Often a state forestry department is responsible for the acquisition and management of state forest lands. The activities and programs of these agencies typically are an essential component of watershed management. Close coordination and cooperation between these agencies and the other "primary" agencies involved in watershed management are needed to ensure that programs do not conflict and to maximize the benefits and cost-effectiveness of all programs.

Additionally, while nearly every natural resources resource management agency has some type of environmental education programs, these typically are narrowly focused, dealing with a particular program. The growing importance of nontraditional pollution sources such as stormwater and nonpoint sources requires the development and implementation of a broad-based environmental curriculum that begins teaching children in kindergarten and continues all the way through their senior year of high school. Each of us must understand the basic interrelationships of the air, land, and water and how our everyday activities can and do contribute to the degradation of our natural systems. We must re-establish the ethic of stewardship, and the best way to accomplish this is through the education of our youth.

## Example State Watershed Management Initiatives

Several states have developed and implemented some or many of the watershed management program components discussed above. In recent years, states have begun to try to integrate ongoing programs into a more comprehensive watershed management framework. Within this publication can be found papers that describe or discuss state programs such as Delaware and Florida, regional programs such as the Puget Sound (Washington) Management Program and the San Francisco Bay Program, and local programs such as the Prince George's County (Maryland) and Summit County (Ohio) programs.

One of the ways in which existing programs, especially planning and regulatory programs, can evolve into an integrated watershed approach is demonstrated by the ongoing efforts in North Carolina. The North Carolina Division of Environmental Management (NCDEM) has developed a plan in which basins, not stream reaches, are the basic unit of water quality management. The objectives of North Carolina's Basinwide Water Quality Management Initiative include (6):

- Identify priority problem areas and pollution sources that merit particular pollutant control, using modifications of rules (e.g., basin criteria) and increased enforcement.
- Determine the optimal water quality management strategy and distribution of assimilative capacity for each of the 17 major river basins within the state.
- Prepare, in cooperation with local governments and citizens, comprehensive basinwide management plans that set forth the rationale, approaches, and long-term management goals and strategies for each basin.
- Implement innovative management approaches that protect the state's surface water quality, encourage the equitable distribution of assimilative capacity, and allow for sound economic planning and growth.

The whole-basin initiative is envisioned as a fully integrated approach to water quality assessment and management. It integrates planning, monitoring, modeling, point source permitting and control, nonpoint source control, and enforcement within a basin. NCDEM has rescheduled its NPDES permit activities so that permit renewals within a given basin will occur simultaneously and will be repeated at 5-year intervals.

One of the difficulties in implementing a basin-wide approach is the setting of priorities, the establishment of a rotating schedule among the basins, and the correlation of management needs (monitoring, planning, permitting, enforcement) with staff and resource allocations. North Carolina prioritized and scheduled its 17 basins based on consideration of the nature and extent of known problems, a basin's importance in terms of human use, the availability of data, and staff workload balancing.

For each basin in turn, North Carolina will perform the 15-step process outlined below (6):

1. Compile all existing relevant information on basin characteristics and water quality.
2. Define the water quality goals and objectives for water bodies within the basin. Revise as necessary as more data are obtained.
3. Identify the critical issues (e.g., water supply protection, shellfish harvesting) and current water quality problems within the basin. Determine the major factors and sources (point, nonpoint, habitat degradation) that contribute to the problems.
4. Prioritize the basin's water quality concerns and critical issues. Ensure public participation and input from other government agencies and nongovernment groups.
5. Define the subbasin management units using basin hydrology, physiographic boundaries, problem areas, and critical issues.
6. Identify needs for additional information.
7. Collect additional information.
8. Analyze, integrate, and interpret the information collected. Revisit Steps 2 through 5 in light of the new information.
9. Determine and evaluate the management options for each management unit in the basin.
10. Select final management approaches for the basin and targeted subbasins.
11. Complete the draft whole basin management plan. Perform additional modeling and other analyses to finalize wasteload allocations.
12. Distribute the draft plan for review and comment, and conduct public hearings.
13. Revise the plan as appropriate in response to comments. Ensure adoption of the plan by the state's environmental management commission.
14. Implement the management approaches, including point and nonpoint source controls.
15. Monitor the program's success and update the plan every 5 years.

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# *The Evolution of Florida's Stormwater/Watershed Management Program*

**Eric H. Livingston**
**Florida Department of Environmental Regulation,**
**Tallahassee, Florida**

## Abstract

Research conducted during the late 1970s as part of the Section 208 Water Quality Management Program identified pollutant loading from stormwater discharges as the major source of water quality degradation in Florida. This paper reviews the evolution of Florida's stormwater regulatory program, from its initial emphasis on controlling stormwater problems from new development to its current emphasis on reducing pollutant loading from existing development. The philosophical and technical basis for the program are discussed, as are the program's major components. The paper emphasizes how the program is beginning to address the retrofitting of existing "drainage systems."

Developing and implementing a statewide stormwater management program requires several key components. Research must be undertaken to develop statewide rainfall distribution statistics, determine stormwater pollutant loading characteristics, determine the effectiveness of various stormwater treatment practices, and identify key design criteria for each type of best management practice. Education is essential and must be targeted at many different audiences: design engineers, state and local government staff and elected officials, construction personnel, inspectors, maintenance staff, and citizens. Dedicated funding sources at both state and local levels are very important, especially if the program is to achieve the desired environmental benefits and for retrofitting. Most importantly, integration of stormwater regulatory programs with other resource management programs on a watershed basis must occur for maximum environmental results and cost-effectiveness.

## 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, the Everglades "River of Grass," and the coral reefs of the Keys. Abundant surface-water resources include over 20 major rivers and estuaries and nearly 8,000 lakes. Plentiful ground-water aquifers provide over 90 percent of the state's residents with drinking water. Add the state's climate and it's 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 its population is still growing rapidly, although not at the 900 people per day (300,000 per year) rate that occurred throughout the 1970s and 1980s.

Florida's natural systems, especially its surface- and ground-water 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 very natural beauty that brought residents and tourists to Florida. Extensive destruction of wetlands, bulldozing of beach and dune systems, continued saltwater intrusion into freshwater aquifers, 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 its growth as the environmental movement in the nation and the state gained strength in the early 1970s. Florida's natural resources management programs have evolved over a 20-year period. 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, and local agencies.

The evolution of Florida’s watershed management program typically involves the following sequence: 1) concern about a specific “pollutant” or problem creates a resource/environmental management program which usually begins by focusing on “new sources” (site basis); 2) over time, as new sources are controlled and the effectiveness of the program increases, the focus shifts to cleaning up “older sources” (watershed or regional basis); 3) ultimately, the focus shifts to integrating the program with similar ones to eliminate any duplication and to improve efficiency and effectiveness.

## Florida’s Stormwater Program: The Beginning

Section 208 of the Federal Clean Water Act required the development of areawide water quality management plans to control point and nonpoint sources of pollution. As part of Florida’s program conducted during the late 1970s and early 1980s, many investigations were undertaken to assess the impacts of stormwater and the effectiveness of various best management practices (1). These studies demonstrated that stormwater, whether from agriculture, forestry, or urban lands, was the primary source of pollutant loading to Florida’s receiving waters. Subsequently, it was concluded that the ability to meet the Clean Water Act objective of fishable and swimmable waters would require the implementation of stormwater programs to reduce the delivery of pollutants from stormwater discharges.

Recognition of this problem, along with the availability of federal funds, led Florida to draft regulations to control stormwater in the late 1970s. The first official state regulation specifically addressing stormwater was adopted in 1979 as part of Chapter 17-4, Florida Administrative Code (FAC). Chapter 17-4.248 was the first attempt to regulate this source of pollution, which, at the time, was not very well understood. Under Chapter 17-4.248, the Florida Department of Environmental Regulation (DER) based its decision to order a permit on a determination of the “insignificance” or “significance” of the stormwater discharge. This determination seems reasonable in concept; however, in practice, such a decision can be as variable as the personalities involved. What may appear insignificant to the owner of a shopping center may actually be a significant pollutant load into an already overloaded stream.

In adopting Chapter 17-4.248, DER intended that the rule would be revised when more detailed information on nonpoint source management became available. About a year after adoption, DER began reviewing the results of research being conducted under the 208 program. DER also established a stormwater task force with membership from all segments of the regulated and environmental communities. A revised stormwater rule, Chapter 17-25, FAC, was developed over 2 years, involving more than 100 meetings between department staff and the regulatory interests, and the dissemination of 29 official rule drafts for review and comment. The rule was adopted by the state’s Environmental Regulation Commission (ERC) and became effective in February 1982. The adopted rule required a stormwater permit for all new stormwater discharges and for modifications to existing discharges that were modified to increase flow or pollutant loading.

The stormwater rule had to be implemented within the framework of the federal Clean Water Act. The act establishes two types of regulatory requirements to control pollutant discharges: technology-based effluent limitations, which reflect the best controls available considering the technical and economic achievability of those controls; and water quality-based effluent limitations, which reflect the water quality standards and allowable pollutant loadings set up by state permit (2). The latter approach can be developed and implemented through biomonitoring based on whole effluent toxicity, making it very applicable to stormwater. Florida’s tremendous growth, the accompanying creation of tens of thousands of new stormwater discharges, and the lack of data on stormwater loading toxicity made this approach unimplementable, however.

Guidance on the development of stormwater regulatory programs and the role of water quality criteria has been issued by the U.S. Environmental Protection Agency (EPA) (3). The guidance recognizes that best management practices (BMPs) are the primary mechanism to enable the achievement of water quality standards. For the purposes of this paper, a BMP is a control technique that is used for a given set of site conditions to achieve stormwater quality and quantity enhancement at minimal cost. Further, the guidance recommends that state programs include the following steps:

- Design of BMPs based on site-specific conditions; technical, institutional, and economic feasibility; and the water quality standards of the receiving waters.
- Monitoring to ensure that practices are correctly designed and applied.
- Monitoring to determine both the effectiveness of BMPs in meeting water quality standards and the appropriateness of water quality criteria in reasonably ensuring protection of beneficial uses.
- Adjustment of BMPs when it is found that water quality standards are not being protected to a designed level, and/or evaluation and possible adjustment of water quality standards.

Proper installation and operation of state-approved BMPs should achieve water quality standards. While water quality standards are to be used to measure the effectiveness of BMPs, EPA recognizes that there should be flexibility in water quality standards to address the impacts of time and space components of stormwater as well as naturally occurring events. If water quality standards are not met, then the BMPs should be modified, the discharge should cease, or, in some cases, reassessment of the water quality standards should be undertaken.

## Rationale for Stormwater Rule Standards

The overriding standards of the stormwater rule are the state's water quality standards and appropriate regulations established in other DER rules. Therefore, an applicant for a stormwater discharge permit must provide reasonable assurance that stormwater discharges will not violate state water quality standards. Because of the potential number of discharge facilities and the difficulties of determining the impact of any facility on a water body or the latter's assimilative capacity, DER decided that the stormwater rule should be based on design and performance standards.

The performance standards established a technology-based effluent limitation against which an applicant can measure the proposed treatment system. Compliance with the rule's design criteria created a presumption that the desired performance standards would be met, which, in turn, provided a rebuttable presumption that water quality standards would be met. If an applicant wants to use BMPs other than those described in the rule, then a demonstration must be made that the BMP provides treatment that achieves the desired pollutant removal performance standard. Actual design and performance standards are based on a number of factors:

- Stormwater management goals: Stormwater management has multiple objectives, including water quality protection, flood protection (volume, peak discharge rate), erosion and sediment control, water conservation and reuse, aesthetics, and recreation. The basic goal for new development is to ensure that postdevelopment peak discharge rate, volume, timing, and pollutant load do not exceed predevelopment levels. BMPs are not 100-percent effective, however, in removing stormwater pollutants, while site variations can also make this goal unachievable at times. Therefore, for the purposes of stormwater regulatory programs, DER (water quality) and the state's regional water management districts (WMDs) (flood control) have established performance standards based on risk analysis and implementation feasibility.
- Rainfall characteristics: An analysis of long-term rainfall records was undertaken to determine statistical distribution of various rainfall characteristics such as storm intensity and duration, precipitation volume, and time between storms. It was found that nearly 90 percent of a year's storm events occurring anywhere in Florida produce a total of 2.54 cm (1 in.) of rainfall or less (4). Also, 75 percent of the total annual volume of rain falls in storms of 2.54 cm or less. Finally, the average interevent time between storms is approximately 80 hr (5).
- Runoff pollutant loads: The first flush of pollutants refers to the higher concentrations of stormwater pollutants that characteristically occur during the early part of the storm, with concentrations decaying as the runoff continues. Concentration peaks and decay functions vary from site to site depending on land use, the pollutants of interest, and the characteristics of the drainage basin. Florida studies (6, 7) indicated that for a variety of land uses the first 1.27 cm (0.5 in.) of runoff contained 80 to 95 percent of the total annual loading of most stormwater pollutants. First flush effects generally diminish, however, as the size of the drainage basin increases and the percent impervious area decreases because of the unequal distribution of rainfall over the watershed and the additive phasing of inflows from numerous small drainages in the larger watershed. In fact, as the drainage area increases in size above 40 ha (100 ac), the annual pollutant load carried in the first flush drops below 80 percent because of the diminishing first flush effect.
- BMP efficiency and cost data: Numerous studies conducted in Florida during the Section 208 program generated information about the pollutant removal effectiveness of various BMPs and the costs of BMP construction and operation. Analysis of this information revealed that the cost of treatment increased exponentially after "secondary treatment" (removal of 80 percent of the annual load) (8).
- Selection of minimum treatment levels: After review and analysis of the above information, and after extensive public participation, DER set a stormwater treatment objective of removing at least 80 percent of the average annual pollutant load for stormwater discharges to Class III (fishable/swimmable) waters. A 95-percent removal level was set for stormwater discharges to sensitive waters such as potable supply waters (Class I), shellfish harvesting waters (Class II), and Outstanding Florida Waters. DER believed that these treatment levels would protect beneficial uses and thereby establish a relationship between the rule's BMP performance standards and water quality standards.

## BMP Treatment Volumes and Design Criteria/Guidelines

The current stormwater treatment volumes for various BMPs are set forth in Table 1. Since adoption of the stormwater rule in 1982, the design criteria and treatment volumes have been revised several times as new

**Table 1. BMP Treatment Volumes for Stormwater Discharges to Class III Waters**

| | |
|---|---|
| **Swales** | Infiltration of 80 percent of the runoff generated by a 3-yr/1-hr storm (typically about 5.1 cm [2 in.] of runoff). |
| **Retention** | Off-line infiltration of the first 1.25 cm (0.5 in.) of runoff or the volume calculated by 1.25 times the percent imperviousness of the project area, whichever is greater. On-line infiltration must treat an additional 1.25 cm of runoff above the volume required for off-line treatment. |
| **Detention With Filtration** | Filtration of detention volume. |
| **Wet Detention** | Detention of the first 2.54 cm (1 in. of runoff) or the volume calculated by 2.5 times the percent imperviousness of the project area, whichever is greater. |
| **Wetlands** | Same as for wet detention. |

Notes: Discharges to sensitive waters must treat 50 percent more stormwater volume and may require infiltration pretreatment.
Discharges to sinkhole watersheds must treat the first 2 in. of runoff (Suwannee River WMD criterion).

information becomes available about the field effectiveness of various types of BMPs.

In addition to the stormwater treatment volumes, other design and performance standards have been set to ensure that BMPs function optimally to attain the stormwater treatment goal and other management objectives (9). These guidelines will be discussed for each of the BMPs currently being used extensively in Florida.

### *Swales*

Swales are defined by Chapter 403, Florida Statutes (FS), as manufactured trenches that:

- Have a top width-to-depth ratio of the cross section equal to or greater than 6:1, or side slopes equal to or greater than 3 ft horizontal to 1 ft vertical.
- Contain contiguous areas of standing or flowing water only following a rainfall event.
- Are planted with or have stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.
- Are designed to take into account soil erodibility, soil percolation, slope, slope length, and drainage area so as to prevent erosion and reduce pollutant concentration of any discharge.

Swale treatment of stormwater is accomplished primarily by infiltration of runoff and secondarily by adsorption and vegetative filtration and uptake (10). Recent investigations have concluded that Florida soil, slope, and water table conditions essentially preclude the use of swales as the sole BMP to treat stormwater (11). Therefore, the greatest utility of swales is as a pretreatment BMP within a BMP treatment train stormwater system. Infiltration pretreatment can be easily accomplished by using raised storm sewer inlets within the swale, or by elevating driveway culverts or using swale blocks to create small retention areas.

### *Retention*

Off-line retention areas, which receive the first flush volume only while the later runoff is diverted to a flood control BMP, are the most effective stormwater treatment practice. Treatment is achieved through diversion and infiltration of the first flush, thereby providing total pollutant removal for all stormwater that is retained on site. To reduce operation needs, increase aesthetics, and reduce the land area needed for stormwater treatment, retention areas should be incorporated into a site's landscaping and open-space areas. Effectiveness of retention areas can be increased and ground-water impacts decreased by:

- Infiltrating the stormwater treatment volume within 72 hr or within 24 hr if the retention area is grassed.
- Grassing the retention area bottom and side slopes, which reduces maintenance and maintains soil infiltration properties.
- Maintaining at least 3 ft between the bottom of the retention area and seasonal high water tables or limerock.
- In karst-sensitive areas, using several small, shallow infiltration areas to prevent formation of solution pipe sinkholes within the system.

Exfiltration trenches typically are used in highly urbanized areas where land is unavailable for retention basins. They consist of a rock-filled trench surrounded by filter fabric in which a perforated pipe is placed. The stormwater treatment volume is stored within the pipe and exfiltrates out of the perforations into the gravel envelope and into the surrounding soil. Pretreatment with catch basins to remove sediments and other debris is essential to prevent clogging. To extend longevity and reduce maintenance, exfiltration systems should always be off-line.

### *Detention With Filtration*

Detention with filtration systems were proposed as an alternative to retention for small projects (less than 8 acres) in those areas of Florida where local conditions, especially flat topography and high water tables, prevent infiltrating the stormwater treatment volume. The filters must consist of 2 ft of natural soil or other suitable fine-textured granular media that meet certain specifications, including:

- Filters must have pore spaces large enough to provide sufficient flow capacity so that the filter permeability is equal to or greater than the permeability of the surrounding soil.
- The design shall ensure that particles within the filter do not move.
- When sand or other fine-textured material other than natural soil is used for filtration, the filter material 1) will be washed (less than 1 percent silt, clay, or organic matter) unless filter cloth is used to retain such materials within the filter, 2) will have a uniformity coefficient between 1.5 and 4.0, and 3) will have an effective grain size of 0.20 to 0.55 mm in diameter.
- Be designed with a safety factor of at least two.
- Will recover the treatment volume (bleed down) within 72 hr.

Filters are placed in the bottom or sides of detention areas, where the filtered stormwater is collected in an underdrain pipe and then discharged. Experience has shown that these filters are very difficult to design and construct. Operation is also difficult because of low hydraulic head, and maintenance is nearly impossible. It is not a question of if a filter will clog, only when it will clog. In addition, filters are designed to remove particulate pollutants and do not remove dissolved pollutants such as phosphorus or zinc. Therefore, filtration systems are not recommended for use except under very special conditions and where a full-time maintenance entity such as a local government will assume such responsibilities.

### *Wet Detention*

Wet detention systems consist of a permanent water pool, an overlying zone in which the stormwater treatment volume temporarily increases the depth while it is stored and slowly released, and a shallow littoral zone (biological filter). In addition to their high pollutant removal efficiencies (12), wet detention systems can also provide aesthetic and recreational amenities, a source of fill for the developer, and even "lake front" property, which brings a premium price.

Wet detention criteria are listed in Table 2. These have been developed to take full advantage of the biological, physical, and chemical assimilation processes occurring within the wet detention system. If the system is designed as a development amenity, the use of pretreatment BMPs integrated into the overall stormwater management system is highly recommended to prevent algal blooms or other perturbations that would reduce the aesthetic value. Raised storm sewers in grassed areas such as parking lot landscape islands, swale conveyances, and perimeter swale/berm systems along the detention lake shoreline are techniques that have been used frequently.

**Table 2. Wet Detention Guidelines**

1. Treatment volume as per Table 1.
2. Treatment volume slowly recovered in no less than 120 hr with no more than half of the volume discharged within the first 60 hr following the storm:
   - Volume in the permanent pool should provide a residence time of at least 14 days.
   - At least 30 percent of the surface area shall consist of littoral area with slopes of 6:1 or flatter that is established with appropriate native aquatic plants selected to maximize pollutant uptake and aesthetic value.
   - Littoral zone plants shall have a minimum 80 percent survival rate and coverage after 2 years. Cattails and other undesirable plants shall be removed.
   - The littoral zone is concentrated near the outfall or in a series of shallow benches ending at the outfall.
   - Side slopes should be no steeper than 4:1 out to a depth of 2 ft below the level of the permanent pool.
   - Maximum depth of 8 to 10 ft below the invert of the discharge structure is recommended. Maximum depth shall not create aerobic conditions in bottom sediments and waters.
   - The flow length between inlets and outlet should be maximized; a length-to-width ratio of at least 3:1 is recommended. Diversion barriers such as baffles
   - An oil and grease skimmer shall be designed into the outlet structure.
   - If the system is planned as a "real estate lake," pretreatment by infiltration is recommended.
   - Inlet areas should include a sediment sump.

### *Wetland Treatment*

Wetland treatment was authorized by the 1984 Henderson Wetlands Protection Act, which allows stormwater treatment in wetlands that are connected to other state waters by a constructed ditch or by an intermittent water course that flows in direct response to rainfall, thereby causing the water table to rise above ground surface. Not only does this take advantage of natural treatment mechanisms but it gives another economic value to wetlands—an incentive to the developer to use, not destroy, the wetland—and it revitalizes ditched and drained wetlands by providing water.

Wetlands may be viewed as nature's kidneys—they store stormwater, dampen floodwaters, transform pollutants, and even retain pollutants, thereby providing natural stormwater treatment (13). Care must be taken, however, to protect the numerous assimilation mechanisms within the wetland plants and sediments. In addition, the wetland hydroperiod—the duration that water stays at various levels—must be protected or restored because it determines the form, function, and nature of the wetland. Therefore, pretreatment practices to attenuate stormwater volume and peak rate and to reduce oil, grease, and especially sediment are essential. The BMP treatment train concept must be used to provide pretreatment, which normally includes a pretreatment lake that is constructed adjacent to the wetland.

The following guidelines are presented for incorporating wetlands into a stormwater management system:

- The treatment volume is per Table 1, with the treatment volume slowly recovered in no less than 120 hr with no more than half of the volume discharged within the first 60 hr following the storm.
- Stormwater must sheet flow evenly through the wetland to maximize contact with the wetland plants, sediments, and microorganisms. Spreader swales, distribution systems, and level spreaders between the pretreatment lake and the wetland have been used extensively.
- Swales should be used for stormwater conveyance throughout the development.
- The hydroperiod must be protected or restored.
- Treatment volume capacity of the wetland is determined by the storage volume available between the normal low and high elevations. These elevations are determined by site-specific indicators such as lichen and moss lines, water stain lines, adventitious root formation, plant community zonation, hydric soils distribution and rack/debris lines.
- Erosion and sediment control during construction is essential because only a few inches of sediment deposited in the wetland will destroy the wetland filter.
- Inflow/outflow monitoring, sediment metal levels, and vegetative transect monitoring are required to help evaluate the effectiveness of these systems and the impacts of stormwater additions to wetlands.

## Administration of the Stormwater Rule

Under the Florida Water Resources Act of 1972, DER, a water quality agency, serves as the umbrella administering agency delegating authority to five regional WMDs whose primary functions historically have been related to water quantity management. Therefore, a second objective in developing the stormwater rule was to coordinate the water quality considerations of DER's stormwater permits with the water quantity aspects of the districts' surface water management permits.

In addition, the delegation of the stormwater permitting program allows for minor adjustments to stormwater rule design and performance standards to better reflect regional conditions. Florida is a very diverse state, with major variations in soils, geology, topography, and rainfall that can directly affect the usability and treatment effectiveness of a BMP. Such problems can be minimized if districts adopt slightly different design and performance standards which are approved by DER before implementation.

Both DER's and the districts' stormwater rules essentially require a new development to include a comprehensive stormwater management system. The system should be viewed as a "BMP treatment train" in which a number of different BMPs are integrated into a comprehensive system that provides aesthetic and recreational amenities in addition to traditional stormwater management objectives.

## The Challenge Ahead

The implementation of Florida's stormwater treatment requirements has been very effective in helping to reduce the stormwater pollutant loading from new development. As a result, the biggest stormwater management problem facing Florida is how to reduce pollutant loadings discharged by older systems, especially local government master systems constructed before the stormwater rule was implemented. These systems were designed solely for flood protection and rapidly deliver untreated stormwater directly to rivers, lakes, estuaries, and sinkholes.

Establishing a stormwater program to retrofit existing systems presents many technical, institutional, and financial dilemmas. The unavailability and cost of land in urbanized areas make conventional BMPs infeasible in most instances. Current state laws and institutional arrangements promote piecemeal, crisis-solving approaches aimed at managing stormwater within political boundaries, yet stormwater follows watershed boundaries. Land-use planning and management must be fully integrated into the stormwater management scheme. Retrofitting is also prohibitively expensive, and many local governments are already short of funds. Therefore, solving our existing urban stormwater problems requires comprehensive, coordinated, creative approaches and technology.

Following is a brief discussion of some of the essential elements of a comprehensive long-term effort to reduce pollutant loadings from older stormwater systems.

### *Watershed Management*

A watershed approach that integrates land-use planning with the development of stormwater infrastructure is essential. After all, it is the intensification of land use and the increase in impervious surfaces within a watershed that create the stormwater and water resources management problems. Consequently, a watershed management team effort, involving state and local governments together with the private sector, is necessary. In fact, local governments are the primary team member because they determine zoning and land use, issue building permits and inspect projects, and have code enforcement powers that can help to ensure that stormwater systems are properly operated and maintained.

Local governments need to identify and map the existing natural stormwater system: the creeks, wetlands, flood plains, drainageways, and natural depression areas. Once mapped, these areas need to be zoned for conservation or low-intensity uses compatible with the functions provided by the natural system. The existing constructed stormwater system must also be mapped, and essential characteristics such as pipe size, drainage areas, and invert elevations must be determined. This information should then be fully integrated with the existing and future land-use plan for the watershed and a master stormwater management plan developed and implemented. The Growth Management Act of 1985, which requires all local governments to adopt comprehensive plans addressing current and future land use with infrastructure needs, establishes a base structure that could promote a watershed management approach.

### *Treatment Requirements for Older Systems*

Numerous problems inherent in a highly urbanized area prevent the application of new development stormwater treatment standards from being imposed on older systems. Instead, a “watershed loading” concept is proposed which considers the beneficial uses of the receiving waters and the total stormwater load that can be assimilated by the receiving waters. The actual treatment level would depend on the watershed’s total allowable loading, which is based on citizen desires for certain beneficial uses of the receiving water. The amount of load reduction needed to restore or maintain the desired beneficial uses of the receiving waters is known as the pollutant load reduction goal (PLRG).

### *Selective Targeting*

The extremely high cost of retrofitting older urban stormwater systems also implies a need for careful evaluation of pollutant reduction goals. A long-term (25 to 40 years) plan based on prioritization of watersheds such that existing systems are selectively targeted for modification is needed to ensure that citizens receive the greatest benefit (pollutant load reduction, flood protection) for the dollar. The upgrading of older systems must also be coordinated with other already planned infrastructure improvements such as road widenings. An excellent example of this approach is the Orlando Streetscape Project. While downtown streets were torn up for this downtown renovation, the existing stormwater system was modified by the addition of off-line exfiltration systems to reduce pollution loads to downtown lakes.

Nonstructural BMPs and source controls also must be used extensively to reduce stormwater pollution from already developed areas. Improved street sweepers that pick up the small particles (<60 microns) that contain high concentrations of metals and other pollutants could also prove valuable in reducing stormwater loadings, especially from downtown business districts where other BMPs usually are infeasible. Education programs for the general public and for professionals involved in stormwater management also are vital. Citizens must understand how their everyday activities contribute to stormwater pollution. For example, citizens should not discard leaves, grass clippings, used motor oil, or other material into swales or storm sewers. Getting youth and citizen groups involved in storm sewer stenciling projects (“Dump No Wastes, Drains To Lake”) is an excellent way of reducing dumping of potential pollutants into these conveyances. Even more importantly, comprehensive training and certification programs are needed for those in the private and public sectors who design, construct, inspect, operate, and maintain stormwater management systems.

### *Funding*

The cost of providing needed stormwater infrastructure improvements to address current and future flooding and water quality problems is gigantic. Yet local governments are already struggling financially, and traditional revenue sources such as property taxes cannot be relied on to pay for stormwater management. Instead, a dedicated source of revenue based on contributions to the stormwater problem is needed. The stormwater utility can provide this. The city of Tallahassee implemented Florida’s first stormwater utility in October 1986, and over 50 local governments have followed this example.

### *Innovative BMPs*

The infeasibility of using traditional BMPs to reduce stormwater pollutant loads in highly urbanized areas means that creative and innovative BMPs are needed. For example, alum injection within storm sewers was used in Tallahassee to reduce stormwater loadings to Lake Ella (14). A sonic flow meter measures storm sewer flow, causing a flow-proportional dose of aluminum sulfate to be injected and mixed with the polluted stormwater. As the alum mixes with the stormwater, a small floc is produced which attracts suspended and dissolved pollutants by adsorption and enmeshment into and onto the floc particles. The floc then settles to the lake’s bottom sediments, gradually blanketing and incorporating into the sediments and thereby reducing internal recycling of nutrients and metals. Other advantages of alum injection include excellent pollutant reduction (>85 percent) and relatively low construction and operations costs, especially for the highly urbanized areas. This type of system has been installed at several locations in Florida with exceptional treatment efficiencies.

Porous concrete consists of specially formulated mixtures of Portland cement, uniform open-graded coarse aggregate, and water. When properly mixed and installed, porous concrete surfaces have a high percentage of void space which allows rapid percolation of rainfall and runoff. Porous concrete is being used widely in Florida, especially for parking lots, and could be an important BMP to reduce stormwater loadings in highly urbanized areas. Recent field investigations of porous concrete parking areas that have been in place for up to 12 years revealed that the infiltration capacity of the concrete has not decreased significantly, a major concern (15). Further information about the use, design, and construction of porous concrete surfaces is available (15).

Regional stormwater systems that manage stormwater from several developments or an entire drainage basin offer many advantages over the piecemeal approach that relies on small, individual onsite systems. They provide economies of scale in construction, operation, and maintenance. Regional systems can also help manage stormwater from existing and future land uses and will be a central part of any retrofitting program. The use of regional systems is another good reason for a watershed management approach that fully integrates land use and stormwater management.

### *The Southeast Lakes Program—A Model*

Many of the above elements of a watershedwide master stormwater planning approach are being implemented by the city of Orlando. The city has adopted an excellent local stormwater ordinance and developed a fine community education program and a prioritized urban lake management program (16). One of the most innovative programs is the Southeast Lakes Project, which is designed to correct flooding problems and to reduce stormwater pollutant loads to 15 urban lakes and 58 drainage wells that currently convey untreated stormwater to an aquifer. A corrective watershed management plan was cooperatively developed by the city, its consultants, DER, and the St. Johns River WMD. The project was initiated not because of enforcement of water quality standards but because of a loss of beneficial uses and local citizen desires and perceptions. Modifications to the existing stormwater systems will be made over a 10-year period, with treatment requirements based on "net environmental improvement" and total watershed load.

One of the most important aspects of the project is the use of innovative BMP designs that promote multiple objectives and take advantage of city-owned properties. At Al Coith Park, a spreader swale will be built on the park's perimeter. When it rains, runoff will enter and fill the swale, overtopping the sidewalk berm and sheet flow across the grassed parkland where it will percolate into the ground. At Lake Greenwood, the surrounding city-owned land is being converted into an urban wetland and expanded lake. The wetland and lake is a complex treatment train that incorporates many BMPs into a very aesthetically pleasing stormwater system and park that even includes reuse of stormwater to irrigate the park and adjacent city-owned cemetery. Near the Citrus Bowl, a packed-bed wetland filter has been installed that will treat water from Lake Clear during times of no rainfall. In addition to improved stormwater management, citizens are receiving the added benefits of recreation and open space. In addition, the retrofitting project has stimulated redevelopment and renovation of existing properties, thereby providing citizens with economic benefits as property values rise.

## Chronologic Evolution of Florida's Watershed Management Program

Following is a chronology of the establishment and revision of Florida statutes and programs that are considered cornerstones of the state's overall watershed management efforts. As such, this chronology traces the evolution of Florida's watershed management program.

### *1970*

Chapter 370, FS, created the Coastal Coordinating Council, which was the first state effort at integrating state/regional programs in the protection and use of coastal resources. Initial efforts from 1970 to 1975 focused on a comprehensive resource-based coastal protection program.

### *1972*

A package of land and water planning, regulation, and acquisition programs was created:

- Chapter 380, FS: This creates the Developments of Regional Impact (DRI) and Areas of Critical State Concern (ACSC) land planning and management programs.
- Chapter 373, FS: The Florida Water Resources Act establishes the state's five regional WMDs; designates the Department of Pollution Control as the oversight agency for the WMDs; requires the development of a state water plan; and allows for the regulation of the water resource. WMDs financed by *ad valorem* property taxing authority of up to 1 mil ($1/$1000 value) which is set in the Florida Constitution. NWFWMD millage capped at 0.05 mil.
- Chapter 259, FS: The Land Conservation Act establishes a program, commonly known as the Environmentally Endangered Lands Program, which authorizes the state to purchase critical and sensitive lands; envisioned as a 10-year program investing $200 million and funded by the sale of state bonds.

### *1973*

In Chapter 403, FS, the Florida Environmental Protection Act renames the Department of Pollution Control as the Department of Environmental Regulation and broadens its powers, duties, and programs. This law is the state's general environmental protection act. It is amended almost annually as new environmental concerns and needs arise and as existing programs evolve.

### *1975*

Chapter 163, FS, the Local Government Comprehensive Planning Act and the state's first growth management legislation, was recommended by the first Environmental Land Management Study Committee (ELMS I). The law requires all cities and counties to prepare comprehensive plans which are submitted for review to the state's land planning agency, the Department of Community Affairs, which in turn sends the plans to other state agencies for review and comment. However, the LGCPA contains no "teeth." Local governments are under no statutory requirement to revise their plans by incorporating the comments and recommendations made by the state reviewing agencies. Furthermore, they are not required to pass land development regulations to implement their plans.

### *1976*

Implementation by EPA and the states of Section 208 of the 1972 Clean Water Act occurs, requiring the development of Areawide Water Quality Management Plans. This was the first national program directed at the assessment and control of nonpoint sources of pollution. In Florida, millions of federal grant dollars allows the DER and 12 "Designated Area Agencies" to undertake extensive research on nonpoint source impacts, sources, controls, control effectiveness, and costs. These data provide the scientific basis for the development and implementation in 1982 of a statewide rule that requires treatment of stormwater for new development and redevelopment projects.

### *1978*

Chapter 380, FS, is amended, adding Part II, the Florida Coastal Management Act, which requires establishment of a program based on existing statutes and rules to serve as a basis for receiving federal approval under the Federal Coastal Zone Management Act of 1972. After approval of the program by the National Oceanic and Atmospheric Administration, Office of Coastal Zone Management, federal grants fund many initiatives to better protect and manage coastal resources. One particular initiative establishes an estuarine watershed management program with emphasis on sediment mapping. This project leads to the development of innovative, reliable coastal sediment sampling, analytical, and assessment techniques.

### *1979*

The first components of the state's Areawide Water Quality Management Plan, the Agriculture Nonpoint Source Plan and the Silviculture Nonpoint Source Plan, are submitted to and approved by EPA. These call for a non-regulatory approach with a regulatory backstop if BMPs required by farm conservation plans are not implemented or if the forestry BMPs required by the state's adopted *Silviculture BMP Manual* are not followed.

Chapter 17-4.248, FAC, the state's first stormwater rule, is adopted by the state ERC as a rule of DER. This rule is intended as a temporary regulation until ongoing research on BMP design and effectiveness is completed. The rule's adoption is controversial, but data collected during from 208 program studies conclusively show that stormwater runoff, especially from urban land uses and highways, is a "pollutant" and therefore should be controlled. Florida's continuing rapid growth makes it imperative that treatment of stormwater, using BMPs, be required for new stormwater discharges that would be "a significant source of pollution."

Chapter 253, FS, is amended to establish the Conservation and Recreation Land (CARL) Trust Fund, which provides additional funding for the purchase of Environmentally Endangered Lands and other lands deemed appropriate and in the public interest by the Governor and Cabinet.

### *1981*

Through action taken by the Governor and Cabinet, the Save Our Coasts land acquisition program is established. The program proposes to spend $200 million over 10 years to purchase coastal lands such as beaches, shorelines, and sensitive areas. Funding is provided by the sale of state bonds backed by documentary stamps as authorized in Chapter 375, FS, which sets policy on how the Land Acquisition Trust Fund is to be administered.

Chapter 373, FS, is amended with the creation of the Save Our Rivers land acquisition program. Administered by the WMDs, this program proposes to spend $320 million over 10 years to purchase wetlands, floodplains, and other lands necessary for water management, water supply, and the conservation and protection of water resources.

### *1982*

Chapter 17-25, FAC, is adopted by the ERC after 2 years of rule adoption workshops and 29 official rule drafts. The rule is technology based rather than water quality based, although the state's water quality standards remain as a backstop should a stormwater discharge be causing violations. A performance standard of 80 percent average annual load reduction is recommended, based on BMP effectiveness and cost data, to establish equity with minimum treatment levels for point source discharges. The rule creates design criteria for various types of BMPs, including retention, detention with filtration, and wet detention. The rule creates "general permits" for certain types of BMPs (i.e., retention, detention with filtration) if they are built to the design criteria. Implementation of the rule is delegated to the South Florida WMD, allowing stormwater treatment requirements to be merged with stormwater quantity (flood control) requirements in one permit.

### *1984*

Chapter 403, FS, is revised to create Section IX, which is known as the Henderson Wetlands Protection Act. This legislation expands the authority of the DER to protect wetlands; establishes administrative procedures to allow landowners to obtain legally binding "wetland lines"; allows the DER to consider fish and wildlife habitat, endangered species, and historical and archaeological resource and other relevant concerns in wetland permitting; allows the use of certain wetlands for incorporation into domestic wastewater and stormwater management systems; transfers wetland regulation for agriculture and forestry activities to the WMDs; and requires the WMDs to protect isolated wetlands and consider fish and wildlife habitat requirements.

The Southwest Florida Water Management District (SWFWMD) receives delegation of the stormwater rule.

In the late 1970s and early 1980s, an extensive appraisal of Florida's growth management system was undertaken, which concluded that the existing system was not working. Shaped by the *Final Report of the Governor's Task Force on Resource Management* (1980) and the second Environmental Land Management Study Committee (ELMS II), a totally new blueprint for managing growth emerged. The ELMS II Committee recommended a comprehensive package of integrated state, regional, and local comprehensive planning; reforms to the DRI law; and coastal protection improvements. The state legislature responded between 1984 and 1986 by enacting several laws. For example, Chapter 186, FS, the State and Regional Planning Act, mandates that the Governor's Office prepare a state comprehensive plan and present it to the 1985 state legislature. It also requires the preparation of regional plans by the state's 11 regional planning councils and provides them with $500,000 for plan preparation.

### *1985*

Chapter 187, FS, the State Comprehensive Plan, originally is envisioned to be a leadership document—the foundation of the entire planning process—with strong, measurable, and strategic goals that will set the course for Florida's growth over the next 10 years. Each state agency is to prepare an agency functional plan, based on the state plan, on which its budget appropriations will be made. Unfortunately, one of the most important elements of the state plan, the development and adoption of a capital plan and budget, is never prepared. However, the plan contains important goals and policies in 25 different areas, including water resources, coastal and marine resources, natural systems and recreation, air quality, waste management, land use, mining, agriculture, public facilities, and transportation.

Important and relevant goals include:

- Ensure the availability of an adequate water supply.
- Maintain the functions of natural systems.
- Maintain and enhance existing surface- and groundwater quality.

Important and relevant policies include:

- Eliminate the discharge of inadequately treated wastewater and stormwater.
- Protect natural systems in lieu of structural alternatives, and restore modified systems.
- Promote water conservation and the use and reuse of treated wastewater and stormwater.
- Establish minimum flows and levels for surface waters to ensure protection of natural systems.

### *1985 to 1986*

Chapter 163, FS, is amended with enactment of the Local Government Comprehensive Planning and Land Development Regulation Act of 1985. This law requires all local governments to prepare local comprehensive plans and implementing regulations, which must be consistent with the goals and policies of the state and regional plans. Numerous state and regional agencies review the local plans and submit their objections, recommendations, and comments to the Department of Community Affairs for transmittal to the local government. This time the local plans must be revised to incorporate the objections, recommendations, and comments. Furthermore, local governments face sanctions from the state that could result in the loss of state funding if adopted local plans are not consistent with the state and regional plans.

Florida's revised growth management system is built around three key requirements: consistency, concurrency, and compactness. The consistency requirement establishes the "integrated policy framework," whereby the goals and policies of the state plan frame a system of vertical consistency. State agency functional plans and Regional Planning Council regional plans must be consistent with the goals and policies of the state plan while local plans are required to be consistent with the goals and policies of the state and appropriate regional plan. Local land development regulations (LDRs) must also be consistent with the local plans goals and policies. Horizontal consistency at the local level also is required to ensure that the plans of neighboring local governments are compatible. Consistency is the strong cord that holds the growth management system together.

Concurrency is the most powerful policy requirement built into the growth management system. It requires state and local governments to abandon their long-standing policy of deficit financing growth by implementing a “pay as you grow system.” Once local plans and LDRs are adopted, a local government may approve development only if the public facilities and services (infrastructure) needed to accommodate the impact of the proposed development can be in place concurrent with the impacts of the development. Public facilities and services subject to the concurrency requirements are roads, stormwater management, solid waste, potable water, wastewater, parks and recreation, and, if applicable, mass transit. Level of service standards acceptable to the community must be established for each type of public facility.

Compact urban development goals and policies are built into the State Comprehensive Plan and into regional plans. Such policies as separating rural and urban land uses, discouraging urban sprawl, encouraging urban in-fill development, making maximal use of existing infrastructure, and encouraging compact urban development form the basis for this requirement.

### *1986*

Chapter 403.0893, FS, is created as the only surviving section of a stormwater management bill that was developed over a 10-month period. The bill was an attempt to put into statute a cost-effective, timely process to retrofit existing drainage systems to reduce the pollutant loadings discharged to water bodies. Only the section creating explicit legislative authority for local governments to establish stormwater utilities or special stormwater management benefit areas is enacted.

The St. Johns River WMD adopts Chapter 40C-42, FAC, and the Suwannee River WMD adopts Chapter 40B-4, FAC. Adoption of these two stormwater management regulations and the addition of staff to implement these programs allows DER to delegate administration of its stormwater treatment rule to these WMDs, which, in turn, allows DER’s stormwater quality permit to be combined with the districts’ stormwater quantity permit.

### *1987*

Chapter 373, FS, 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 WMDs, under DER supervision, to prepare a priority water body list and develop and adopt comprehensive watershed management plans to preserve or restore the water bodies. It provides $15 million from general revenue sources and requires a match from the WMDs. The act does not establish a dedicated funding source, making the program dependent on uncertain annual appropriations from the legislature.

### *1988*

Chapter 17-43, FAC, the SWIM rule, is adopted by the ERC. It sets forth factors to consider in the selection of priority water bodies, specifies the format for SWIM plans to ensure some consistency, and establishes administrative processes for the development and adoption of SWIM plans by the WMDs and for their submittal to DER for review and approval.

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 nonpoint source implementation grants, which are used for BMP demonstration projects and to refine existing nonpoint source management programs. The delineation of the state’s ecoregions (based on river systems), selection of ecoregion reference sites, and modification of EPA’s Rapid Bioassessment Protocols and metrics for use in Florida are initiated.

### *1989*

Chapters 373 and 403, FS, are revised as part of the 1989 stormwater legislation. The legislation clarifies the stormwater program’s multiple goals and objectives; sets forth the program’s institutional framework, which involves a partnership between 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, FS, to add a policy in the Agriculture Element to “eliminate the discharge of inadequately treated agricultural wastewater and stormwater”; further promotes the watershed approach being used by the SWIM program; attempts to integrate the stormwater program, SWIM program, and local comprehensive planning program (but does not succeed); establishes 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 Fund as an incentive to local governments to implement stormwater utilities and provides $2 million.

### *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 is created and includes the goals, policies, and institutional framework for the state's stormwater management program.

DER is designated as the lead agency with responsibility for setting goals for the program, for providing overall program guidance, for overseeing implementation of the program by the WMDs, and for coordinating with EPA, especially with the advent of the new National Pollutant Discharge Elimination System 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 PLRGs; they provide technical assistance to local governments, especially with respect to basin planning and the development of stormwater master plans.

Local governments are the frontlines in the stormwater/watershed management program because 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 those needs to be created 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 goals include:

- Preventing stormwater problems from 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 ensure that the stormwater peak discharge rate, volume, and pollutant loading are no greater after a site is developed than before.

Important minimum treatment performance standards include:

- 80 percent average annual load reduction for new stormwater discharges to most water bodies.
- 95 percent average annual load reduction for new stormwater discharges to Outstanding Florida Waters, which are a special class of exceptionally high-quality water bodies.
- 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.

Chapter 375, FS, is amended with the creation of Preservation 2000, a 10-year land acquisition program with a goal of spending $300 million per year. The legislation divided available annual funding among seven programs: CARL, Save Our Rivers (SOR), Florida Communities Trust, State Parks, State Forests, State Wildlife Areas, and Rails to Trails. The program is funded the first year by state bonds backed by an increase in the documentary stamp fee. Unfortunately, a long-term dedicated funding source is not identified, making the program subject to annual legislative appropriations. Between 1972 and 1991, the state's land acquisition programs have invested over $1.5 billion to buy over 1.2 million acres. Equally important, as a result of the state land acquisition programs, 14 Florida counties have created local programs that currently commit up to $600 million for land conservation. Revenue sources for these local land acquisition programs include local option sales tax, impact fees, added property taxes, and local bonds.

### *1991*

Chapter 40C-42, FAC, is completely revised by the St. Johns River WMD to modify the design criteria for stormwater treatment BMPs so that they will achieve the minimum treatment levels set in State Water Policy. Stormwater reuse becomes essential for developments discharging to Outstanding Florida Waters.

Chapter 40C-44, FAC, is adopted by the St. Johns River WMD to regulate certain agricultural pumped discharges (formerly regulated as industrial wastewater) and establishes design and performance criteria for these agricultural stormwater management systems.

The SWFWMD initiates development of an agricultural stormwater management program for certain types of agricultural activities including row crops and citrus. The program includes regulatory incentives to obtain technical assistance from U.S. Department of Agriculture, Soil Conservation Service, or other qualified individuals to prepare and implement a farm-specific resource management plan that contains certain required BMPs.

### *1992*

DER and the WMDs, in response to increasing demands on the state's waters and the increasing number of water quantity and quality problems, begin the development of district water management plans. collectively these district plans, together with the DER's plan, will create the state water management plan. These plans are based on the goals and policies set in State Water Policy and in the state comprehensive plan. For each of four major areas (water supply, water quality, flood protection, natural systems protection), four key planning steps will occur:

- Resource assessment to identify current or anticipated problems.
- Examination of options.
- Declaration of policy.
- Designation of implementation strategies.

Section 314 Federal Clean Lake Program Lake Assessment Grant is obtained to initiate the delineation of lake ecoregions, select lake ecoregion reference sites, and test/validate lake bioassessment sampling protocols and metrics.

***1993***

Chapters 373 and 403, FS, are revised extensively as part of the DER/Department of Natural Resources merger to create the Department of Environmental Protection (DEP) and as a part of the Environmental Permit Streamlining bill. The goals of the streamlining bill are to eliminate duplication, especially in permitting; increase administrative and environmental effectiveness by increasing delegation of programs from DEP to the WMDs; and ensure greater program consistency and integration. Key specific actions of the bill include:

- Moving the “Wetlands Protection Act” from Chapter 403 to Chapter 373, FS, thereby delegating the wetland resource permits to the WMDs except for certain projects that require other types of DEP permits.
- Merging the existing surface water/stormwater management permit with the wetland resource permit to create an environmental resource permit.
- Redefining wetlands based on their hydrology, vegetation, and soils, and requiring the development of a single wetland delineation method that will be used by the DEP, WMDs, and local governments.

Recommendations of the third Environmental Lands Management Study Committee (ELMS III) are enacted into law (with a 180-page act), thereby amending several state laws. The act seeks to strengthen the state planning process by:

- Requiring the Governor to biannually review and analyze the state comprehensive plan and recommend any necessary revisions.
- Requiring the Governor to prepare a new growth management portion of the state comprehensive plan. This is to provide a more detailed and strategic state policy guidance for state, regional, and local governments in implementing the state plan. It is to identify urban growth centers; set strategies to protect identified areas of state and regional environmental importance; and provide guidelines for determining where urban growth is appropriate and should be encouraged. The growth management document must be adopted by the legislature. However, to what extent local comprehensive plans, state agency strategic plans, and regional policy plans must be consistent with the state plan is unknown—to be recommended by the Governor and adopted as law by the 1994 legislature.

The act also provided greater flexibility and less requirements in local comprehensive plans for small cities (≤5,000) and counties (≤50,000); streamlined the plan amendment process by limiting the types of revisions requiring state review and approval; strengthened the local plan evaluation and appraisal process; terminated or made optional the development of regional impact (DRI) process in certain areas and revised the DRI process; and authorized local option gas tax of up to 5 cents.

## Discussion and Recommendations

Florida has established a wide variety of laws, regulations, and programs at the state, regional, and local level to protect, manage, and restore the state’s incredibly valuable yet vulnerable natural resources, especially its water resources. There is no doubt that these programs have been effective in helping to reduce adverse impacts on natural resources resulting from the state’s rapid and continuing growth over the past 20 years. Even with the implementation of these programs, however, many of Florida’s natural resources have been severely strained or degraded. Some of these adverse effects can be attributed to activities that occurred before the implementation of modern watershed management programs, such as the channelization of the Kissimmee River and the creation of the vast drainage canal network south of Lake Okeechobee, both of which are contributing to the decline of Lake Okeechobee, the Everglades, and Florida Bay. Other adverse impacts, though, are directly related to the state’s rapid growth and development during the last 20 years. These include water supply problems, water quality problems, declining habitat, and impacts on endangered species such as the manatee and the Florida panther.

Why are these adverse impacts still occurring given the wide range of watershed management programs that have been implemented in Florida?  What could be done to reduce these effects and possibly restore already degraded areas?  Following is a list of program deficiencies and recommendations to correct them:

- While the statutes enacted by the legislature may be helpful, insufficient resources have been provided to the governmental entities that are to implement the programs. The state’s reliance on sales tax as it primary means of raising “general revenues” means that state revenues are tied closely to economic conditions. Relying on such sources during a recession, especially when population growth is still occurring, means that the state budget is nearly always in crisis. Dedicated sources of funding are needed if watershed management programs are going to compete for limited state resources and have adequate resources to actually achieve their intended benefits.

- The statutes and programs are not fully integrated, leaving gaps in both land planning and water planning programs. In particular, there is a need to better integrate water and land planning and regulatory programs. The local government growth management program needs to be more closely connected to state and regional water management programs. The requirements set forth in State Water Policy and in the district/state water management plans need to be used by local governments in their land-use planning programs. These local plans need to be consistent among all state, regional, and local programs.

- Greater emphasis needs to be placed on ensuring the long-term maintenance and operation of stormwater management systems. Because these systems are a part of the local infrastructure, local governments need to take a more active role in this area. Establishing stormwater operation permits as part of a stormwater utility funded program is an excellent way of providing an economic incentive to a land owner to maintain and operate an onsite stormwater management system properly.

- Greater emphasis needs to be placed on erosion and sediment control on construction sites and on utility installation projects. A major deficiency is ensuring the regular inspection of erosion prevention and sediment control practices. Implementation of a training and certification program for inspectors and contractor supervisors, similar to the Certified Construction Reviewer Program in Delaware, is needed.

- Retrofitting existing drainage systems to reduce their pollutant loading is one of the biggest, most difficult, and most expensive challenges the state has ever faced. One of the major problems in meeting this challenge is the need to develop new stormwater treatment techniques that are not land intensive. Funding of demonstration projects and for research of new techniques in needed.

- While Floridians are among the most educated citizens in the country with respect to water resources and stormwater management issues, more education is needed to help gain citizen support for watershed management programs. The state's environmental education program needs to focus on establishing a comprehensive natural resources management curriculum that begins in kindergarten and continues all the way through high school. Additionally, because of the large number of people who are moving to Florida, especially retirees, continuous education programs are needed to educate these people about the vulnerability and importance of Florida's natural resources.

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# *The State of Delaware Sediment Control and Stormwater Management Program*

**Earl Shaver**
**Delaware Department of Natural Resources and Environmental Control,**
**Dover, Delaware**

## Institutional Philosophy

Before submitting proposed legislation regarding stormwater management or sediment control, representatives of the State of Delaware Department of Natural Resources and Environmental Control (DNREC) conducted an extensive educational program to document the serious nature of water quantity and quality problems that exist statewide. This problem documentation was successful in that elected officials, affected industries, and the general public acknowledged the need for a comprehensive approach to sediment control and stormwater management. The statewide legislation was unanimously approved in four committees and on the floor of both the state senate and the house of representatives. The local conservation districts were instrumental in their support of the legislation. In addition, the regulations detailing the legislative requirements were approved with no negative comments after an extensive educational process and with the assistance of a regulatory advisory committee.

A basic premise of the program is that sediment control during construction and stormwater quantity and water quality control postconstruction are all components of an overall stormwater management program that functions from the time that construction is initiated through the lifespan of the constructed project (Figure 1). Program implementation was initiated on July 1, 1991, and the initial emphasis of the program is to prevent existing flooding or water quality issues from worsening. The intent is to limit further degradation until more comprehensive, watershed-specific approaches, as detailed in the state legislation and regulations, can be adopted.

## Program Structure

The structure of the sediment and stormwater management program is based on the premise that ultimate program responsibility must rest with the state. In the case of Delaware, the state agency responsible for program implementation is DNREC. DNREC is the ultimate approval authority. Local conservation districts and jurisdictions, however, may request delegation of four program components:

- Sediment control and stormwater management plan approval.
- Inspection during construction.
- Postconstruction inspection of permanent stormwater facilities.
- Education and training.

The sediment control and stormwater management plan review and approval process must be completed before any building or grading permits are issued. Criteria for plan review and approval are contained in state regulations, and design aids and handbooks have been developed or approved by DNREC. One important distinction of the Delaware program is that the delegated local agency handles day-to-day inspection responsibilities.

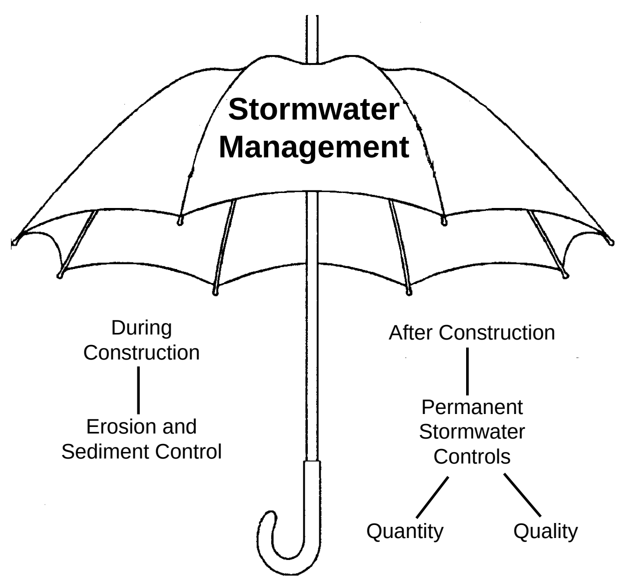


**Figure 1. Stormwater management.**

Projects for which site compliance cannot be achieved are transferred to the state, where progressive, aggressive enforcement is carried out. State enforcement options include civil and criminal penalty provisions.

## Control Practices

Site control practices (Figures 2 and 3) are grouped into two categories: temporary practices during construction and permanent practices for postconstruction runoff. Sediment control practices, designed for temporary site control, must comply with the *Delaware Erosion and Sediment Control Handbook*. This handbook details numerous practices that are available for use depending on applicability. The plan review process ensures that the sediment control practices are located appropriately.

In addition to the traditional structural controls that the handbook contains, the regulations have several requirements that are important to providing overall site control. Site stabilization must be accomplished if the disturbed areas are not being actively worked for a period in excess of 14 days. In addition, unless modified for a specific type of project, no more than 20 acres may be disturbed at any one time to facilitate phasing of a project.

The regulations specifically require that water quality must achieve an equivalent removal efficiency of 80 percent for suspended solids. From a permanent stormwater management standpoint, initial consideration for control must be a pond that has a permanent pool of water. These wet ponds also have an extended detention requirement placed on them in addition to peak flow control of larger storms. Ponds having a normal pool are preferred over either normally dry extended detention ponds or infiltration practices due to their documented performance records and the ability of wet ponds to reduce downstream nutrient loadings. Wet ponds, if properly designed, also can be an amenity to the community where they are placed. A major emphasis is being placed on constructed wetlands as a primary stormwater treatment system in upland areas. The Delaware program does not encourage the use of existing wetlands for stormwater treatment.

Another option for site control is the use of infiltration practices. These practices are allowed but not encouraged due to their potential for clogging and concern over

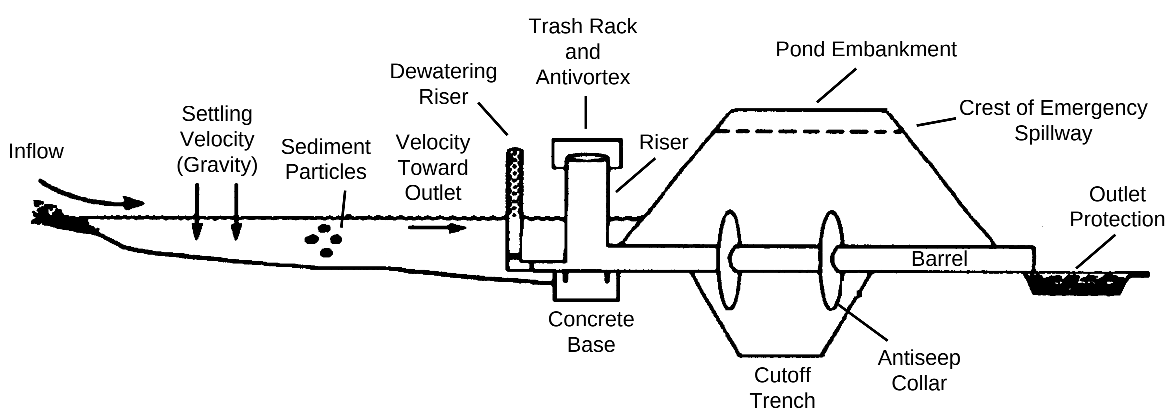


**Figure 2. Sediment pond (to be converted to permanent stormwater management facility).**

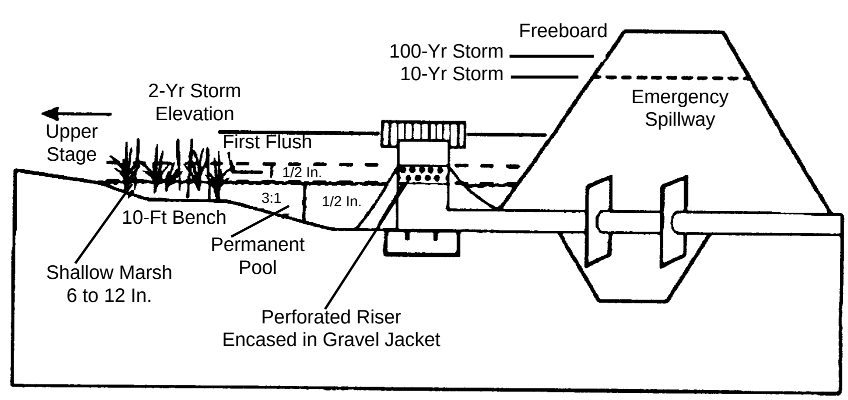


**Figure 3. Extended detention pond.**

ground-water pollution. Experience in other jurisdictions has demonstrated the potential that infiltration practices have for clogging. Where infiltration practices are used, upslope and downslope impacts in the event of clogging are carefully considered during the plan review process. Infiltration of stormwater runoff is a necessary component of an overall stormwater management program, but critical safeguards relating to filtering of stormwater and ground-water pollution concerns must be considered before design approval.

Filtration of runoff also must be a program component either as a stand-alone practice or in conjunction with other practices, primarily infiltration. Common filtration practices generally rely on vegetative filtering of runoff over filter strips or through swale systems. On highly impervious sites, vegetative filters often are not feasible; in these situations, a sand filter design may be appropriate for initial water quality treatment (Figure 4). Several variations in sand filter designs may be applicable from site to site, but defined design criteria must be followed if the system is to be effective at pollutant removal.

## Unique Features

Several features of the Delaware program are unique. The regulations clearly require that stormwater management practices achieve an 80-percent reduction in suspended solids load after a site has been developed. The only other state to present a similar performance criteria is Florida. The 80-percent figure was selected based on a review of documented stormwater practice performances around the country. That level of performance can be achieved with present technology application. Long-term removal rates in excess of 80 percent may require extraordinary measures such as water reuse, which may be required on a local basis but which is not practical from a statewide perspective.

The concept of delegation of program components is fairly unique with respect to program implementation. In Delaware, each aspect of program implementation may be delegated, with DNREC acting as a safety net in the event that a conservation district or a local government fails to adequately implement an aspect of the program. The initial concept of delegation was developed in Maryland for inspection of sediment control; the concept was expanded in the Delaware law and regulations to encompass all aspects of program implementation. The actual interaction of state and local program implementers has quickly become a partnership effort, with the state providing technical expertise and educational training while the conservation districts and local governments provide for actual program implementation.

A major way in which the Delaware program is unique is in the use of privately provided inspectors (Certified Construction Reviewers). The land developer on larger projects (over 50 acres in size or where the state or delegated inspection agency requires) must provide sediment control and stormwater inspectors to assist the appropriate governmental inspection agency. These inspectors must attend and pass a DNREC course on inspection, inspect active construction sites at least once a week, and submit an inspection report to the developer/contractor and the inspection agency on their findings and recommendations. The inspection agency still must periodically inspect the site to ensure the adequacy of site controls, but the designated inspector reduces the frequency of inspection for the inspection agency. Failure to accurately record site conditions or failure to notify either the contractor/developer or inspection agency of site deficiencies may jeopardize the desig-

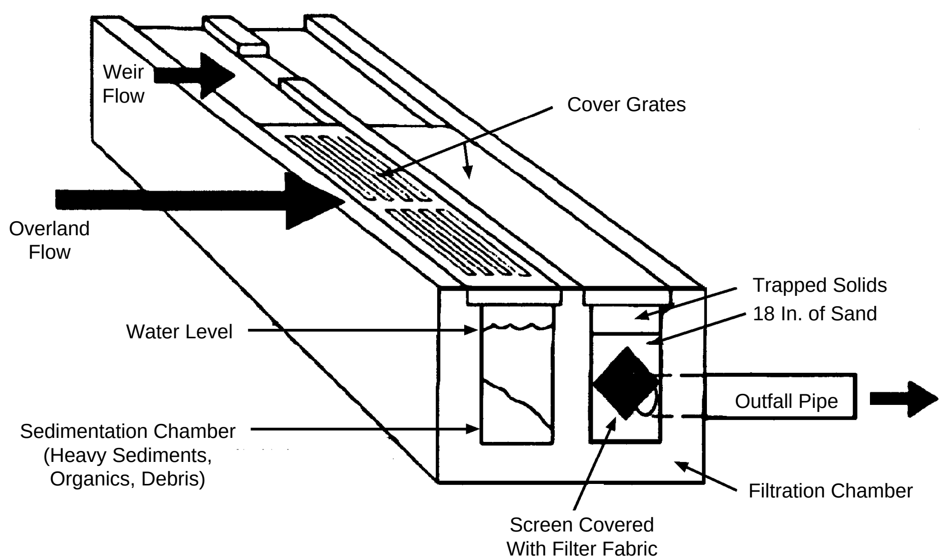


**Figure 4. Sand filter design.**

nated inspector's certification, which could be grounds for enforcement action against the contractor/developer.

Another important concept that is becoming increasingly popular among states implementing sediment control programs is the requirement that contractors must have a responsible individual(s) certified as having attended a DNREC course for sediment control and stormwater management. The Delaware course lasts approximately 4 hours and attempts to acquaint contractors with the importance of good site erosion and sediment control and stormwater management, as well as with their responsibilities under the law. The contractor certification program is extremely popular with contractors and reduces the "we-they" problems that often exist in regulatory programs.

## Evolution

The program discussed above represents the initial phase of program implementation in Delaware. The next step relates to addressing stormwater management from a watershed perspective. The sediment and stormwater regulations contain a Designated Watershed concept that allows for the design and construction of practices on a watershed basis that, when coupled with land-use planning, wetland restoration, and other nonstructural practices, reduces existing flooding problems or improves existing water quality. The expectation is that one watershed will be designated in each county to serve as a model for other watersheds. These watersheds will be studied from a hydrologic, water quality, and stream habitat and diversity standpoint, and alternative land uses and stormwater controls will be considered along with their impact on water quality. Based on the results of the watershed study, a recommended approach for watershed protection will be developed in conjunction with local government officials that presents a blueprint for future resource protection in these Designated Watersheds.

Funding is another area that must be addressed if the initial program is to be expanded. The state law and regulations provide a framework for expanding traditional funding mechanisms with more innovative types of funding. The regulations contain significant information on the consideration of stormwater utilities (user fees) as an alternative to permit fees or general funding. The stormwater utility is expected to accompany the Designated Watershed concept as a mechanism to fund the watershed studies, planning, design, implementation of practices, and the maintenance of completed stormwater management structures.

One area that has not been satisfactorily addressed at this time is the maintenance of residential stormwater management structures. Commercial stormwater management structure maintenance is not expected to present a significant problem, because one entity is generally responsible for overall site maintenance; residential stormwater management structure maintenance, however, is not so easily assured. At this time, residential maintenance is generally the responsibility of a community association, but eventually that responsibility must become a public responsibility if maintenance is to be assured. If that shift of responsibility is to occur, a dedicated funding source, such as a stormwater utility, will have to be implemented.

The issue of land use and its relationship to water quantity and water quality needs to evolve if resource protection is to be accomplished. Significant effort will be expended in educating local government officials on the importance of wetlands, open space, greenways, cluster development, and other options to conventional "cookie cutter" zoning. The Designated Watershed approach will provide specific details on the benefits of alternative land-use approaches and their impacts on water quality and aquatic resources.

An effective stormwater management program must be multifaceted in its approach and implementation. It must cross conventional lines that are based on an erroneous assumption that total resource protection can be provided through the implementation of structural controls that are considered only after entire site utilization has been maximized. Land-use limitations, dedicated open space, vegetated buffer areas, and reduced impervious areas are all components of an overall resource protection strategy. The implementation of a structural control strategy alone will only reduce the rate of resource decline. That type of program needs to be implemented as a first step, but programs should recognize the need for continued evolution for true resource protection to occur.

# *Section 6217 Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*

**J.W. Peyton Robertson, Jr.**
**National Oceanic and Atmospheric Administration,**
**Office of Ocean and Coastal Resource Management, Washington, DC**

## Abstract

In recognition of the fact that over half of the nation's population lives in coastal areas and that nonpoint source pollution remains a significant limiting factor in attaining coastal water quality goals, Congress enacted Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). Section 6217 establishes a requirement that states with federally approved coastal zone management programs develop and implement coastal nonpoint pollution control programs to address nonpoint sources affecting coastal waters.

These coastal nonpoint programs are to be implemented through changes to state nonpoint source pollution programs approved by the U.S. Environmental Protection Agency (EPA) under Section 319 of the Clean Water Act and through changes to state coastal zone management programs approved by the National Oceanic and Atmospheric Administration (NOAA) under Section 306 of the Coastal Zone Management Act. The central purpose of Section 6217 is to strengthen the links between federal and state coastal zone and water quality management programs and thereby enhance state and local efforts to manage land uses that affect coastal water quality. States are to achieve this by implementing 1) management measures in conformity with guidance published by EPA under Section 6217(g) of CZARA, referred to as the (g) guidance or the management measures guidance, and 2) additional management measures developed by states where necessary to achieve and maintain water quality standards.

In addition to the (g) guidance, NOAA and EPA have jointly produced program development and approval guidance that outlines the requirements for state coastal nonpoint programs. The program guidance outlines the process by which states will develop their programs and submit them for approval. It also includes the criteria by which EPA and NOAA will evaluate state coastal nonpoint programs.

This paper provides an overview of the program development and approval guidance by briefly describing the elements of the program development process and the necessary components for an approvable state program. Included in this description are coastal zone boundary modification recommendations; identification of nonpoint sources to be addressed; implementation of management measures; additional management measures/critical areas; enforceable policies and mechanisms; program coordination, public participation, and technical assistance; and the program approval process.

## Overview

As part of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Congress enacted a new Section 6217, entitled "Protecting Coastal Waters." This new section requires states with federally approved coastal zone management programs to develop and implement coastal nonpoint pollution control programs (referred to here as coastal nonpoint programs).[1] These coastal nonpoint programs are to build and expand upon existing efforts to control nonpoint pollution by state coastal zone management and nonpoint source control agencies.

Section 6217(g) of the statute requires the U.S. Environmental Protection Agency (EPA), in consultation with the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service, and other federal agencies, to publish and periodically update "guidance for specifying management measures for sources of nonpoint pollution in coastal waters." This

[1]The term "state" refers to states, territories, and commonwealths having coastal management programs approved under Section 306 of the Coastal Zone Management Act. There are currently 29 such programs.

technical guidance, or (g) guidance, was published on January 19, 1993. A companion guidance document, entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, was also released on the same date. Though the program guidance was not required by the statute, NOAA and EPA developed the guidance in an effort to identify clearly the necessary elements for an approvable state coastal nonpoint program.

The statute sets out a two-tiered process for implementing management measures. First, states are to implement technology-based management measures throughout the Section 6217 management area. Second, states must implement additional management measures where water quality standards are not attained or maintained. The states are to determine these additional measures. The program guidance further explains the justification necessary to exclude any nonpoint source category or subcategory from the first tier of a state coastal nonpoint program and sets out the components each state program should include. The program guidance provides for a threshold review process that allows states to work with NOAA and EPA to evaluate their existing nonpoint programs and identify gaps that need to be filled. Finally, the program guidance establishes a process for submitting programs to NOAA and EPA for approval and a schedule for program development, approval, and implementation.

The focus of this paper is the “nuts and bolts” of each state coastal nonpoint program. Each program will vary due to unique differences in both state physiographic features and government structure. Even so, the basic components of a state coastal nonpoint program need to include those elements identified in the statute and discussed in the program guidance.

## Statutory Requirements

Section 6217 requires that several elements be included in each state coastal nonpoint program in order to receive NOAA and EPA approval. These basic statutory requirements, excerpted from the program guidance, appear below. State programs must:

- Be closely coordinated with existing state and local water quality plans and programs developed pursuant to Sections 208, 303, 319 and 320 of the Clean Water Act, and with state coastal zone management programs.
- Provide for the implementation, at a minimum, of management measures in conformity with the guidance published under Section 6217(g) to protect coastal waters generally.
- Provide for the implementation and continuing revision from time to time of additional management measures that are necessary to attain and maintain applicable water quality standards and protect designated uses with respect to:
  - Land uses that, individually or cumulatively, may cause or contribute significantly to a degradation of 1) coastal waters not presently attaining or maintaining applicable water quality standards or protecting designated uses or 2) coastal waters that are threatened by reasonably foreseeable increases in pollution loadings from new or expanding sources.
  - Critical coastal areas adjacent to coastal waters that are failing to attain or maintain water quality standards or that are threatened by reasonably foreseeable increases in pollutant loadings.
- Provide for technical and other assistance to local governments and the public to implement additional management measures.
- Provide opportunities for public participation in all aspects of the program.
- Establish mechanisms to improve coordination between state agencies and between state and local officials responsible for land-use programs and permitting, water quality permitting and enforcement, habitat protection, and public health and safety.
- Propose to modify state coastal zone boundaries as the state determines is necessary to implement NOAA recommendations under Section 6217(e), which are based on findings that modifications to the inland boundary of a state coastal zone are necessary to more effectively manage land and water uses to protect coastal waters.

## Program Development

### *The Section 6217 Management Area*

The statute requires that NOAA conduct a review of each state’s existing coastal zone boundary to determine whether or not the area encompassed by the boundary includes the land and water uses that have “significant” impacts on the state’s coastal waters. The impact of land and water uses on coastal waters is considered both “individually and cumulatively.” In cases where NOAA finds that modifications to the inland boundary of a state’s existing coastal zone are necessary to more effectively manage land and water uses, NOAA is required to recommend a modification to the existing coastal zone. Although expressed in terms of a recommendation that a state modify its coastal zone boundary, NOAA’s recommendation also defines what NOAA and EPA believe should be the geographic scope of that state’s coastal nonpoint program, i.e., the “6217 management area.”

NOAA conducted a review of each state’s coastal zone boundary, using existing national data to evaluate land

and water uses within the state. The national data included information on such parameters as population, land area, harvested crop land, and soil loss from crop land. Information was compiled for each state and summarized in a draft document entitled *National Summary: State Characterization Reports.*

In evaluating indicators of nonpoint source pollution, NOAA analyzed data for areas within the state's existing coastal zone and for areas within and outside of coastal watersheds. NOAA used the smallest U.S. Geological Survey mapping unit as a definition of the coastal watershed. In cases where indicators suggested that nonpoint pollution beyond the coastal watershed might have a significant impact on coastal waters, NOAA assessed the need to further extend the boundary to encompass these land and water uses. The area finally recommended by NOAA for inclusion (both the land area encompassed by the existing coastal zone boundary and any area landward of the existing boundary) constitutes the 6217 management area.

NOAA recently provided recommendations to states for modifying their existing coastal zone boundaries. These boundary recommendations generally conform with the state coastal watershed boundaries, except in cases where indicators of nonpoint pollution beyond the coastal watershed appear significant. In such cases, NOAA recommends that an additional area landward of the coastal watershed be included in the 6217 management area. In addition to the boundary recommendations, NOAA issued a set of draft criteria that states may use in developing their response to the boundary modification recommendation. The final boundary determination will be accomplished through the state response to the NOAA recommendation and a public review and comment process at the state level. States have the option of either extending their existing coastal zone boundary inland or exercising other state authorities within the 6217 management area.

### Identification of Nonpoint Sources To Be Addressed

The basic premise of Section 6217 is that technology-based controls should be implemented for all nonpoint sources that, either individually or cumulatively, have significant impacts on coastal waters. There need not be a demonstration that an individual source has an impact on water quality. In this sense, Section 6217 is akin to the technology-based approach of the point source program under the Clean Water Act. For program approval, states are to implement management measures throughout the 6217 management area for all nonpoint source categories (e.g., agriculture) and subcategories (e.g., confined animal facilities) identified in the management measures guidance. States also may include management measures for other sources (e.g., mining) not identified in the guidance if the state determines such measures are necessary to protect coastal waters generally.

The program guidance provides for exclusions of nonpoint source categories and subcategories under certain circumstances. If the state can demonstrate that the source is neither present nor anticipated in the 6217 management area, the source may be excluded. States also may exclude sources that do not, individually or cumulatively, present significant adverse effects to living coastal resources or human health. It should be noted that the burden of proof is on the state to demonstrate that the application of the management measures to the remaining sources will protect coastal waters generally. In other words, if a state wishes to exclude a particular nonpoint source category from management measures implementation, the state must demonstrate that the nonpoint category does not (and is not reasonably expected to) present significant adverse effects to living coastal resources or human health.

For either type of exclusion, the state must provide documentation of the rationale and data used to justify the exclusion. The program guidance includes certain factors that may be considered in exclusions. They are as follows:

- Pollutant loadings or estimates of loadings from the sources.
- Intensity of land use.
- Ecological and human health risk associated with the source.

NOAA and EPA will review the information provided by the state to determine if the category or subcategory may be excluded from the coastal nonpoint program.

### Implementation of the (g) Management Measures

State programs need to provide detailed information on how each of the management measures will be implemented. The program guidance includes a description of the information to be included in the coastal nonpoint program for each nonpoint category and subcategory. This information includes the scope, structure, and coverage of the state program; the designated lead agency and supporting agencies that will implement the program; a program implementation schedule with milestones; enforceable policies and mechanisms to ensure management measure implementation; interagency coordination mechanisms; a process to identify practices to implement the management measures; operation, maintenance, and inspection procedures to ensure continuing performance of the measures; and monitoring activities to evaluate the effectiveness of the measures.

States may already have programs in place that can be incorporated into the coastal nonpoint program. States need to provide information on how these existing programs can be used to implement the management measures and identify where necessary changes will be made. For example, a state may have a program that requires local ordinances for erosion and sediment control. Because the program guidance requires "enforceable policies and mechanisms" at the state level, the state would have to show some means of ensuring local implementation of erosion and sediment control. This could be in the form of backup state enforcement or some other state oversight of local programs.

Where states do not have existing programs to address a given nonpoint category or subcategory, they will have to develop new authorities and programs to ensure implementation of the management measures. This may include developing new state authority. Both existing and new programs need to be incorporated into the coastal nonpoint program.

### *Additional Management Measures/Critical Areas*

The program guidance requires states to implement additional management measures under two conditions:

- Where coastal water quality remains impaired even after implementation of the (g) measures.
- In areas whose function is critical to water quality.

States must first identify waters that are threatened or impaired as a result of nonpoint pollution impacts. Land adjacent to these waters plays a particularly important role in attaining or maintaining water quality. There may be situations where new and expanding land uses could result in further impacts to threatened or impaired waters from nonpoint sources, beyond those controlled by the (g) measures. The purpose of additional management measures in this case is pollution prevention to avoid water quality problems that might otherwise develop.

Additional management measures also are required for coastal waters that are not attaining or maintaining applicable state water quality standards or protecting designated uses. There are two instances where states will need to implement additional management measures due to water quality impairments. First, if a state has identified waters that are failing to meet water quality standards and determines that existing pollution prevention activities and/or the implementation of the (g) measures will not be adequate to achieve water quality standards, the state will have to implement additional measures for those waters at the time of program approval. The second is following implementation of the (g) measures and monitoring to evaluate effectiveness of the (g) measures. If a state determines that water quality impairments (as a result of nonpoint sources) exist even after implementation of the (g) measures, the state will have to implement additional management measures.

### *Enforceable Policies and Mechanisms*

Besides the provisions for state coastal nonpoint programs found in Section 6217, CZARA also amended Section 306 of the Coastal Zone Management Act (CZMA) to require that (before approving a coastal zone management program) NOAA finds " . . . the management program contains enforceable policies and mechanisms to implement the applicable requirements of the coastal nonpoint pollution control program of the state required by Section 6217 . . ." (Section 306(d)16). The CZMA also includes a definition of "enforceable policy": "[t]he term 'enforceable policy' means state policies which are legally binding through constitutional provisions, laws, regulations, land use plans, ordinances, or judicial or administrative decisions, by which a state exerts control over private and public land and water uses and natural resources in the coastal zone."

The program guidance outlines a variety of both regulatory and nonregulatory approaches that a state may design to meet the requirement for enforceable policies and mechanisms. Examples of regulatory approaches include permit programs, local zoning requirements, and state laws. Nonregulatory approaches could include economic incentives (such as cost-share programs) or disincentives (such as taxes or user fees). Nonregulatory approaches must be backed by enforceable state authority to ensure management measure implementation.

Several existing state programs to control nonpoint sources are backed by state laws. In other cases, state requirements are delegated to local authorities for implementation or rely on state funds, which provide cost-share monies for implementing practices. For a state coastal nonpoint program to be approvable, the state needs to demonstrate that these programs are ultimately subject to state enforcement authority. An example of how this might work for a cost-share program that is currently voluntary is for the state to back up the voluntary program with a "bad actor" provision in state law. In cases where participation in the voluntary program does not result in implementation of the management measures, the state would have the ability to penalize the "bad actors" or those who failed to take advantage of the voluntary opportunity.

Traditional regulatory approaches could offer more direct state oversight of management measures implementation. A state could issue general permits for specific source categories that include certain criteria that must be met by all those who meet the category definition. Conditions on the general permit would allow tailoring of requirements for site-specific circumstances. Issuance of individual permits (such as those issued by many states for septic systems) could also be used for a specific entity.

### *Program Coordination, Public Participation, and Technical Assistance*

The program guidance requires several other program elements, including provision for administrative coordination, public participation, and technical assistance. These elements are critical to successful implementation of coastal nonpoint programs because they provide necessary linkages between state, regional, and local governments; between government agencies and the public; and between government agencies and affected user groups. Such linkages ensure the involvement of a variety of players and, if well developed, build strong support for programs from the grass-roots level to the state capitol.

Administrative coordination is inherent in the involvement of state coastal zone management agencies and state water quality agencies as equal partners in the development of coastal nonpoint programs. These ties need to be further enhanced through the involvement of other state agencies (such as state forestry, state agriculture, and state health departments) and with local governments who will be instrumental in implementing programs at the ground level. Such relationships can be further defined and solidified through memoranda of agreement, joint permitting processes, cross training of staff, and interagency committees.

Public participation is an integral part of the coastal nonpoint program because public support is necessary to ensure effective program development and implementation. The program guidance requires that states must provide opportunities for public participation in all aspects of the coastal nonpoint program. Specifically, each state needs to demonstrate that its program has undergone public review and comment before submittal to NOAA and EPA for approval.

Technical assistance is particularly important in providing regional and local governments with needed direction on how to implement the provisions of state coastal nonpoint programs. The statute outlines a variety of technical assistance areas, including "assistance in developing ordinances and regulations, technical guidance, and modeling to predict and assess the effectiveness of such measures, training, financial incentives, demonstration projects, and other innovations to protect coastal water quality and designated uses." Technical assistance also will be necessary for affected user groups and the public. The program guidance also includes assurances that NOAA and EPA will continue to provide technical assistance to states as they develop and implement their programs.

## Program Submission and Approval

States have 30 months from the publication of the final (g) guidance to develop their coastal nonpoint programs. The final (g) guidance document was published on January 19, 1993, giving states until July 19, 1995, to submit their programs (see timeline below). During this period, states have opportunities to meet with NOAA and EPA and discuss their progress on program development. The program guidance establishes a threshold review process whereby NOAA and EPA conduct an initial review of a state's program to address key issues and decision points. Threshold review is voluntary but provides an opportunity for states to identify gaps in their programs early in the process, giving a better idea of what to expect when the program is finally submitted for approval. It also helps focus limited resources where they can be used in the most efficient and effective manner.

In addition to threshold review, the program guidance sets out a conditional approval provision for state programs that are submitted without all of the necessary elements for final approval. NOAA and EPA recognize (under limited circumstances) that a state may submit a program for which all necessary enforceable policies and mechanisms are in place but that the state may need additional time to develop state, regional, or local authorities to implement the state requirements. Under such circumstances, NOAA and EPA may grant conditional approval of a state program for a period of 1 year. Final approval of the program would depend on the state's ability to demonstrate that all necessary enforceable policies and mechanisms are in place. A conditional approval will not affect the date by which states must achieve full implementation of the (g) measures. Full implementation still must proceed and be completed within 3 years of the first federal approval action, whether that approval is conditional or not.

## Summary

Table 1 presents a timeline for coastal nonpoint program development, approval, and implementation.

**Table 1. Coastal Nonpoint Program Development, Approval, and Implementation**

| Date | Process |
|---|---|
| January 1993 | Final (g) measures and program approval guidance issued |
| January 1993 | Coastal nonpoint program development: threshold review (optional), formal/informal |
| July 1995 | States submit final Section 6217 coastal nonpoint programs |
| January 1996 | EPA/NOAA complete review of state programs (program approval) |
| January 1996 | State begins implementation of (g) measures |
| January 1999 | Full implementation of (g) measures |
| January 2001 | Completion of 2-year monitoring period |
| January 2004 | Full implementation of additional management measures |

## *Compliance With the 1991 South Carolina Stormwater Management and Sediment Reduction Act*

**K. Flint Holbrook and William E. Spearman, III**
**South Carolina Land Resources Conservation Commission,**
**Columbia, South Carolina**

### Abstract

The 1991 Stormwater Management and Sediment Reduction Act is comprehensive legislation intended to address the management of stormwater runoff from a watershed perspective. The Act establishes a statewide program making requirements consistent across political boundaries. It gives local governments several options to address specific problems though the creation of stormwater utilities or designated watersheds. Considerations are made for citizen complaints and input into program development and operation.

### Introduction

Stormwater management and sediment reduction is an integral part of nonpoint source pollution control. Amendments to the federal Clean Water Act in recent years have emphasized stormwater management and sediment control as basic parts of National Pollutant Discharge Elimination System (NPDES) permitting. Several states recognized erosion and sediment control as a major problem in the early 1970s. States had used different approaches, ranging from comprehensive statewide regulatory legislation (e.g., North Carolina) to the voluntary approach of enabling legislation to allow local governments to enact ordinances to regulate erosion and sediment control on the local level. Traditionally, stormwater management was not part of enabling legislation or statewide programs.

In the early to mid 1980s, some states began to incorporate stormwater management into these programs. The Clean Water Act amendments strengthened the case for attaching the stormwater management issue to the erosion and sediment control programs. To date, several states have implemented combined programs.

South Carolina passed enabling legislation in 1971 to allow local governments to pass ordinances to regulate erosion and sediment control. This approach met with very little success; only 22 local ordinances were passed in 22 years. In 1983, the Erosion and Sediment Reduction Act was passed to regulate state-owned lands. This act was to set an example for local programs. The act exempted the South Carolina Department of Highways and Public Transportation by requiring them to establish a program of their own.

In 1991, the South Carolina General Assembly recognized the increasing problems from years of mismanagement of stormwater runoff. On May 27, 1991, Governor Carroll Campbell signed the 1991 Stormwater Management and Sediment Reduction Act. Pursuant Regulation 72-300 became effective June 26, 1992.

### Requirements of the Act

The 1991 act sets minimum standards for program development for control of sediment and water quantity statewide. The act allows local governments to establish stormwater utilities and designated watersheds. It also mandates a statewide regulatory program for stormwater management and sediment reduction.

The intent is to delegate program components to local governments or conservation districts. There are four components to the program: plan review, inspection, enforcement, and education and training. Criteria for delegation of each component is set forth in the regulations. Any or all of the components may be delegated. The delegation is valid for 3 years. The South Carolina Land Resources Conservation Commission provides oversight of the local program to ensure its proper operation. In the event that delegation is not requested, the commission operates the program within that jurisdiction or until a local entity requests delegation. The local government has first right of refusal to request delegation. If the local government chooses not to request delegation, the local conservation district may request the delegation.

The commission retains jurisdiction of certain activities to the exclusion of all others. The commission will permit activities by persons with eminent domain, the federal government, and all local governments.

## Requirements for Individual Site Development

Minimum standards are established for individual site development. There are important dates that should be recognized when determining specific requirements for site development. The effective date of the act was May 27, 1992. The effective date of Regulation 72-300 was June 26, 1992. All sites with land-disturbing activities that affect 5 acres or more and that began on or after October 1, 1992, are required to permit through this program regardless of local program status. Beginning July 1, 1993, any land-disturbing activity starting on or after that date in the fifteen most populated counties as listed in Section 72-303 must permit through the program. Additional counties are phased in for 1994 and 1995. Size limits have been set for land disturbances from 0 to 2 acres as a reporting requirement following guidance in 72-307(H). Permits for land disturbances of 2 to 5 acres are required under the guidelines of 72-307(I). Land disturbances greater than 5 acres must follow Section 72-307.

## Site-Specific Requirements

The site-specific requirements have some general similarities to the federal Clean Water Act requirements for construction. One of the major differences addresses the quantity of water released. These regulations are broken into different parts according to the stage of the land-disturbing activity.

Postconstruction requirements include both quantitative and qualitative controls. For quantity control, post-development release rates for the 2-year/24-hour and 10-year/24-hour design storms are controlled to the 2-year/24-hour and 10-year/24-hour predeveloped release rates. Quality controls for the first flush are implemented where ponds are the proposed method of control. A wet pond requires capture of the first half inch of runoff volume from the impervious areas site. This flow can be mixed with the clean permanent pool volume and discharged over 24 hours. A dry pond requires that the first 1 inch of runoff volume from impervious areas is captured and released over 24 hours. The first flush must be separated from the additional flow into the dry basin.

Where ponds are not the proposed method of control, nonstructural controls are required. Riparian vegetation strips, grass waterways, sand filters, and other measures to meet postconstruction water quality concerns are acceptable alternatives.

During construction, the requirement is qualitative, dealing exclusively with control of offsite discharge of sediment. A performance standard of 80 percent removal (total suspended solids in versus total suspended solids out) or an efficiency of an effluent standard of 0.5 mL/L peak effluent settable solid concentration, whichever is most lenient, must be achieved. Sites with 10 disturbed acres draining to a single point are required to have a sediment basin. Otherwise, a combination of structural and nonstructural practices may be used. There is no sampling requirement to prove compliance with these standards. Plans are developed using modeling techniques to predict performance of this standard for the 10-year/24-hour design storm.

A construction sequence, one of the most important requirements, is required as part of the overall plan. The sequence, which is developed by the project designer, contains all site activities, from installing tree protection to final landscaping and paving. Close compliance with the construction is required. The contractor must follow this sequence, with modifications allowed for unforeseen circumstances; however, the sequence is not normally modified.

## Inspection and Enforcement

Site inspection is of primary importance to operations of this program. Without inspection, the program is doomed to failure. Weekly unannounced site inspections are made on each site. Further, a set of approved plans is required to be held on site.

Enforcement provisions in the act provide for fines of up to $1,000 per day. Also, stop-work orders may be issued. These enforcement provisions are used when violations occur and cooperation is not received to correct the problem. There are no criminal penalties associated with violations of this act.

Enforcement actions require that the owner be notified by certified mail of any violation. Land-disturbing activities commencing without a permit are subject to an immediate stop-work order. Violations are cited in the inspection report, with a copy given to the designated day-to-day contact and a copy mailed to the owner. If corrective action is not taken within the specified time frame, a certified letter is mailed to the owner. This letter outlines the corrective action required and the penalties to be assessed.

## Citizen Complaint Process

A citizen may file a complaint concerning any portion of program operation or site-specific regulation. The complaint is filed with the implementing agency for action. If satisfaction is not achieved, a hearing may be requested. This hearing must follow procedures listed in the South Carolina Administrative Procedures Act. If satisfaction is not achieved in this hearing, the complaint may be appealed in the court system.

# *Florida's Growth Management Program*

**Eric H. Livingston**
**Florida Department of Environmental Regulation, Tallahassee, Florida**

## Abstract

Between 1970 and 1990, Florida's population nearly doubled, from 6,791,418 to 12,937,926. Recognizing that this rapid growth—up to 900 people per day—could overwhelm the state's social, economic, and environmental resources, the Florida legislature twice passed growth management acts. This paper reviews the history of growth management in Florida, with emphasis on the differences between the 1975 and 1986 legislation. The state's current growth management program and process is described, focusing on the institutional framework and the relationship to the state's water quality management program. The role of various state and regional resource management agencies in the review and approval of local government comprehensive plans and the implementing land development regulations is discussed, including specific areas of Florida's growth management program that are essential to the management of water resources. The paper also presents examples of goals within the State Comprehensive Plan that can form the foundation for watershed management and the maintenance and restoration of water resources. Lessons learned in the implementation of Florida's growth management program are reviewed, with recommendations made to improve the program's environmental effectiveness.

## Introduction

Florida's citizens and political leaders accepted the notion that the strong and sustained growth that Florida enjoyed after World War II was an unmixed blessing that would ensure economic health with no negative effects. It was assumed that growth not only paid for itself but also produced surplus revenues for state and local governments. Florida's public policy toward growth during the 1950s and 1960s could best be described as "Build now, worry later."

During this period, Florida grew at a phenomenal rate with the population rising from 2,771,305 in 1950 to 6,791,418 in 1970 and to 12,937,926 in 1990. 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.

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 and development decisions were altering the state in a manner that, if left unchecked, could lead to profound, irretrievable loss of the very natural beauty that brought residents and tourists to Florida. Extensive destruction of wetlands, bulldozing of beach and dune systems, continued saltwater intrusion into freshwater aquifers, and the extensive pollution of the state's rivers, lakes, and estuaries were only some of the negative impacts of this rapid growth.

## What Is Growth Management?

Florida is one of eight states to have implemented a growth management program (1). Understanding Florida's growth management system requires a clear understanding of the distinctions between growth management, comprehensive planning, and land/environmental regulations:

- *Growth management* looks at broad issues and at the interrelationship of systems: natural systems, infrastructure, land use, and people. It attempts to assess how well we have provided for the needs of our citizens in the past and on how to determine and provide for the needs of new citizens. Growth management encompasses comprehensive planning, natural resource management, public facilities planning, housing, recreation, economic development, and intergovernmental coordination.
- *Comprehensive planning* is a governmental process for inventorying resources, establishing priorities, establishing a vision of where a community wants to

go, and determining how to get there. It is a systematic way of looking at the different components of a community, county, region, and state.

- *Regulations* are the specific controls applied to different types of development activities to regulate and minimize their negative impacts. Typically, regulations are administered by all levels of government, federal, state, and local. At the local level, land development regulations are the ordinances that implement the local comprehensive plan.

## Comprehensive Planning Versus Regulation

Comprehensive planning allows a community to make decisions about how and where future growth will occur. Comprehensive planning asks, Is this the right location? Is this the right time? Is this the right intensity for the proposed use of the land? Comprehensive planning seeks to prevent problems (social, economic, environmental) before development occurs.

Permitting, on the other hand, asks only, How can we do the best job with this development on this particular site? Permitting is site-specific and seeks only to mitigate the impacts of the land-use decision. Limitations are always inherent in any regulatory program, and comprehensive planning can help to overcome them. Principal among these limitations is the fact that permitting is piecemeal and does not consider cumulative effects. Therefore, regulation and permitting cannot substitute for planning. Both are needed to manage growth effectively and to protect quality of life.

## Growth Management in Florida, Chapter 1

Florida began serious and comprehensive efforts to manage its growth as the environmental movement in the nation and the state gained strength. In 1972, the Florida legislature enacted the first modern package of land and water planning, regulation, and acquisition programs. This package included:

- Chapter 373, Florida Statutes (F.S.), establishing the state's five regional water management districts, requiring the development of a state water plan, and allowing for the regulation of the water resource.
- Chapter 403, F.S., establishing the state's Department of Environmental Regulation and its powers and duties.
- Chapter 259, F.S., establishing the Environmentally Endangered Lands program, which authorized the state to purchase critical and sensitive lands.
- Chapter 380, F.S., creating the Developments of Regional Impact (DRI) and Areas of Critical State Concern (ACSC) programs.

In 1975, at the recommendation of the first Environmental Land Management Study Committee (ELMS I), the Legislature enacted the state's first growth management legislation. Chapter 163, F.S., the Local Government Comprehensive Planning Act (LGCPA), required all cities and counties to prepare a comprehensive plan. These plans were submitted for review to the state's land planning agency, the Department of Community Affairs (DCA), which in turn sent the plans to other state agencies for review and comment.

Despite the legislature's good intentions, the growth management legislation passed in the 1970s contained fatal flaws. First, the LGCPA contained no "teeth." Local governments were under no statutory requirement to revise their plans by incorporating the comments and recommendations that the state agencies involved in the review of the local comprehensive plans had made. Furthermore, they were not required to pass land development regulations to implement their plans. Most importantly, state and local officials never recognized that substantial new funding would have to be provided to make the program work. Funding was essential for the mandated planning, for supporting the costs of infrastructure, and for implementing strategies to manage growth. Finally, the law did not require local governments to ensure that public facilities and services kept up with the demands imposed by population growth. As Florida's population continued to boom in the 1980s, this failure to connect the costs of growth with land-use decisions and population increases resulted in billions of dollars of backlog in public facilities and services, increased strain on existing facilities, and an ever-increasing deficit in the quality of life for Floridians.

## Growth Management in Florida, Chapter 2

In the late 1970s and early 1980s, an extensive appraisal of Florida's growth management system was undertaken; the appraisal concluded that the existing system was not working. Shaped by the Final Report of the Governor's Task Force on Resource Management (1980) and the second Environmental Land Management Study Committee (ELMS II), a totally new blueprint for managing growth emerged. The ELMS II recommended a comprehensive package of integrated state, regional, and local comprehensive planning, reforms to the DRI law, and coastal protection improvements. The legislature responded by enacting the following growth management framework:

- *The State and Regional Planning Act of 1984* (Chapter 186, F.S.) mandated that the Governor's Office prepare a state comprehensive plan and present it to the 1985 legislature. It also required the preparation of regional plans by the state's 11 regional planning councils and provided $500,000 for plan preparation.

- *The 1985 State Comprehensive Plan* (Chapter 187, F.S.) originally was envisioned to be a leadership document—the foundation of the entire planning process—with strong, measurable, and strategic goals that would set the course for Florida's growth over the next 10 years. Each state agency was to prepare an agency functional plan, based on the State Comprehensive Plan, upon which its budget appropriations would be made. Unfortunately, one of the most important elements of the State Plan—the development and adoption of a capital plan and budget—was never prepared.

- *The Local Government Comprehensive Planning and Land Development Regulation Act of 1985* (Chapter 163, F.S.) required all local governments to prepare local comprehensive plans and implement regulations consistent with the goals and policies of the state and regional plans. Numerous state and regional agencies reviewed the local plans and submitted their objections, recommendations, and comments to the Department of Community Affairs for transmittal to the local government. This time, the local plans had to be revised to incorporate the objections, recommendations, and comments. Furthermore, local governments faced sanctions from the state that could result in the loss of state funding if adopted local plans were not consistent with the state and regional plans.

Florida's revised growth management system is built around three key requirements: consistency, concurrency, and compactness:

- The *consistency* requirement established the "integrated policy framework," whereby the goals and policies of the State Plan framed a system of vertical consistency. State agency functional plans and regional planning council regional plans had to be consistent with the goals and policies of the State Plan, while local plans had to be consistent with the goals and policies of the state and appropriate regional plan. Furthermore, the individual elements of each local plan must be internally consistent, a requirement that has the power to make local plans into coherent, meaningful, balanced documents for guiding the future of a community. Local land development regulations (LDRs) must also be consistent with the local plan's goals and policies. Horizontal consistency at the local level also is required to ensure that the plans of neighboring local governments are compatible. Consistency is the strong cord that holds the growth management system together.

- *Concurrency* is the most powerful policy requirement built into the growth management system. It requires state and local governments to abandon their long-standing policy of deficit financing growth by implementing a "pay as you grow system." Once local plans and LDRs are adopted, a local government may approve a development only if the public facilities and services (infrastructure) needed to accommodate the impact of the proposed development can be in place concurrent with the impacts of the development. Public facilities and services subject to the concurrency requirements are roads, stormwater management, solid waste, potable water, wastewater, parks and recreation, and, if applicable, mass transit.

- *Compact* urban development goals and policies are built into the State Comprehensive Plan and into regional plans. Policies such as separating rural and urban land uses, discouraging urban sprawl, encouraging urban in-fill development, making maximum use of existing infrastructure, and encouraging compact urban development form the basis for this requirement.

## Synopsis of the 1985 Growth Management Process

### *Content of Local Comprehensive Plans (2)*

The plans are prepared in accordance with the minimum requirements set forth in Rule 9J-5, Florida Administrative Code (FAC), "Minimum Criteria for Review of Local Government Comprehensive Plans and Determination of Compliance."

#### Who Prepares the Plan?

The local government may designate itself as the local planning agency (LPA) or designate a LPA by ordinance to prepare the plan and recommend it to the local government for adoption. Procedures assuring maximum public input and participation must be implemented by the local government and the LPA.

#### What Is Included in the Plan?

Plans shall consist of materials, written or graphic, including maps, as are appropriate for the prescription of goals, objectives, principles, guidelines, and standards for the orderly and balanced future economic, social, physical, environmental, and fiscal development of the area. The plan must contain the nine required elements and, if the local government population exceeds 50,000, a Mass Transit Element and an Aviation and Port Element.

#### What Are the Required Plan Elements?

These elements must be internally consistent and economically feasible. Each element consists of data analysis along with the setting of goals and policies to achieve desired results. The elements include:

1. *Capital Improvements Element*, which must consider the projected need and location of public facilities over the next 5 years:

a) This element must contain a component with principles for construction of new public facilities or for increasing capacity of existing facilities.

b) A component must also be provided outlining principles for correcting existing public facility deficiencies.

c) The element must set forth standards to ensure availability and adequacy of public facilities.

d) It must establish the acceptable levels of service for all facilities.

2. *Future Land Use Element*, which must include a future land use map. The map and policies of this element must be based on studies, data, and surveys that determine the projected population changes, show the distribution and amount of land for each land use type (e.g., residential, commercial, industrial) needed to accommodate the growth, show the availability of public services, address renewal of blighted areas, and eliminate nonconforming uses.

3. *Traffic Circulation Element*, showing existing and proposed transportation routes needed to achieve the desired level of service based on future population and land uses.

4. *Public Services/Facilities Element*, which establishes the level of service for wastewater, solid waste, stormwater, and potable water. An analysis must be undertaken to determine whether existing facilities are providing current residents with the desired level of service, and whether these facilities can meet the demands for service created by projected future development; to identify any existing or future service deficiencies; to determine strategies and schedules for correcting these deficiencies; and to insert these needed infrastructure improvements into the Capital Improvements Element.

5. *Conservation Element*, to provide principles and guidelines for the conservation, use, and protection of natural resources, including air, water, recharge areas, wetlands, estuarine marshes, soils, beaches, floodplains, rivers, bays, lakes, wildlife and marine habitat, and other natural and environmental resources.

6. *Recreation and Open Space Element*, which must establish a level of service for recreational facilities, set forth how these will be met as the population grows, and ensure public access to beaches.

7. *Housing Element,* with standards and principles to be followed to ensure the provision of housing for existing residents and provide for future growth. It must also include provisions for adequate sites of future housing for low and moderate income persons, for mobile homes, and for group homes.

8. *Coastal Management Element,* which must be prepared by those jurisdictions having a coastline. This element is to set forth policies to maintain, restore, and enhance the overall quality of the coastal zone environment, including wildlife; to protect human life against the effects of natural disasters; and to limit public expenditures that subsidize development in high-hazard coastal areas.

9. *Intergovernmental Coordination Element*, to coordinate the plan with those of adjacent local governments, school boards, special districts, etc.

### *The Plan Adoption and Review Process*

Local plans are submitted to the DCA at a rate of 10 to 15 per month in accordance with the schedule and dates set out in Rule 9J-5, FAC.

The local government sends the proposed plan to DCA for review and written comment. DCA in turn sends copies to other state agencies for review and comment within 45 days. Within 45 days after receiving comments from these other agencies, the DCA issues an Objections, Recommendations, and Comments (ORC) Report, which summarizes the comments received from all of the reviewing agencies. The local government has 60 days to revise the plan, hold a public hearing, and formally adopt it.

Upon adopting the revised plan, the local government sends the adopted plan to DCA. DCA has 45 days to review and issue a legal Notice of Intent to find the plan "in compliance" or "not in compliance." The term "in compliance" means consistent with the State Comprehensive Plan, the Regional Plan, and Rule 9J-5, which sets forth minimum criteria.

If the local plan is found to be not in compliance, the following process occurs:

- A formal Chapter 120, F.S., Administrative Hearing is held, at which the local government can show by a preponderance of evidence that the plan is in compliance. A Final Order upholding or overturning DCA's determination of compliance is sent to the Governor and Cabinet.
- If the plan is not in compliance, the Governor and Cabinet can either specify remedial actions to bring the plan into compliance or impose sanctions on the local government, resulting in the loss of state revenue sharing funds, loss of state funds for road improvements, and loss of eligibility for some grant programs.

If the local plan is found to be in compliance:

- A legal notice of intent is published in a local newspaper.
- Within 21 days, any affected party may file a petition for a formal Chapter 120 hearing to appeal DCA's compliance decision.

- After the hearing, a final order is issued that either upholds or overturns the DCA compliance determination. If overturned, the Governor and Cabinet again can either specify remedial actions or impose sanctions.

### Plan Adoption and Approval Status

As of August 1993, a total of 186 local comprehensive plans were in compliance, while 30 were not in compliance. Another 212 plans had been brought into compliance through a negotiated compliance agreement between the DCA and the local government, and 29 plans that were not in compliance have a pending compliance agreement that has not been signed (3). Of the 259 local comprehensive plans determined to be not in compliance, the compliance issues that caused the findings to be made are summarized in Table 1 (4).

### The Plan Amendment Process

Chapter 163 limits amendments to an adopted comprehensive plan to only twice a year. These amendments must be adopted following the same procedure as when the plan was first adopted. The plan amendment review process is similar to the original plan review process, involving the following steps:

1. The land owner submits a request for plan amendment to the local government. Usually this must include certain data and information to help the local government determine the potential impacts of the proposed amendment.
2. The local government holds a public hearing to determine whether to adopt the proposed plan amendment.
3. Proposed plan amendments are submitted to the DCA for review to ensure consistency with state and regional plans and with Rule 9J-5. DCA transmits the amendment to other state agencies for their review and comment within 30 days. DCA has a total of 45 days to review the amendments; incorporate comments, objections and recommendations from other state agencies; and send the ORC Report to the local government.
4. The local government conducts a public hearing where it can adopt, adopt with modifications, or not adopt the amendment.

**Table 1. Compliance Issues**

| Compliance Issue | Number | Percentage |
|---|---|---|
| Natural resource protection | 198 | 76 |
| Level of service standard | 183 | 71 |
| Land use | 163 | 63 |
| Concurrency management system | 128 | 49 |
| Affordable housing | 89 | 34 |
| Financial feasibility | 84 | 32 |
| Coastal management | 59 | 23 |
| Intergovernmental coordination | 56 | 22 |
| Land development regulation | 21 | 8 |

## *Implementing the Plan: Adopting Land Development Regulations*

A key feature of the 1985 growth management legislation is the requirement that local governments adopt LDRs within 1 year after submission of the revised plan to DCA for formal review. LDRs are defined in Chapter 163, F.S., as "ordinances enacted . . . for the regulation of any aspect of development." They are an exercise of the general governmental police power for the protection of the public health, safety, and welfare. LDRs must address, at a minimum, the following areas:

- Subdivisions.
- Implementation of land-use categories included in the land-use element and map (zoning), along with regulations to ensure the compatibility of adjacent land uses and to provide for open space.
- Protection of potable water wellfields.
- Stormwater management (quantity and quality).
- Protection of environmentally sensitive land.
- Signage.
- Public facilities and services to meet or exceed the established level of service standards.
- Onsite vehicular and pedestrian traffic flow and parking.

The LDRs must be adopted by ordinance, and the adoption process must comply with the notice and public hearing process set forth in Florida law. Finally, the LDRs must be combined into a single land development code.

Unlike local plans, LDRs do not undergo comprehensive state review and approval. The DCA may review and take action on individual LDRs under only two circumstances. The first is for "completeness review," in which the DCA must have reasonable grounds to believe that a local government has totally failed to adopt any of the required LDRs. "Reasonable grounds" means that DCA has received a letter(s) from a party or parties stating facts that show the local government has failed to adopt one or more of the required LDRs. DCA can then require a local government to submit its LDRs for review. DCA then enters into a period of review and consultation with the local government to determine whether the local government has complied with statutory requirements. If DCA determines that a local government has failed to adopt one or more required LDRs, it notifies the local government within 30 days. The local government then must adopt the LDRs and submit them to DCA. If the local government fails to adopt the LDRs, DCA institutes action in circuit court to require adoption of the required LDRs.

The second type of state review is to assure that the LDRs "implement and are consistent with the local comprehensive plan." This review looks more closely at the actual content and substance of the ordinances. This review can only be initiated by a "substantially affected person" (citizen), however, and it cannot be initiated by the DCA. A consistency challenge must occur within 12 months after the final adoption of the LDR. The substantially affected person must petition DCA to initiate a Chapter 120 administrative hearing. If DCA reviews the information in the petition and determines that the LDRs are not consistent with the plan, then DCA requests an administrative hearing. If DCA reviews the information in the petition and determines that the LDRs are consistent with the plan, then the affected party can request an administrative hearing. If the Final Order from the administrative hearing finds the LDR is inconsistent, then the Governor and Cabinet determine what types of sanctions will be imposed on the local government.

### *Comprehensive Plans and the Protection of Natural Resources*

A main purpose of the comprehensive planning program is to maintain, restore, and protect Florida's very valuable, vulnerable natural resources. The goals and policies set forth in the State Comprehensive Plan along with the requirements in Rule 9J-5, which set forth specific objectives and policies that must be included in each plan element, provide the basis for the protection of natural resources.

Within the State Comprehensive Plan, goals and policies that specifically address minimizing impacts of various activities on natural resources and the general conservation, protection, and proper use and management of natural resources are found within the Water Resources, Coastal/Marine Resources, Natural Systems and Recreation Lands, Air Quality, Waste Materials, Land Use, Mining, Agriculture, Public Facilities, Conservation, and Transportation Elements. The following are examples of these goals and policies.

For the Water Resources Element, the goal is to "assure the availability of an adequate supply of water . . . and . . . maintain the functions of natural systems and the overall present level of surface and ground-water quality. Florida shall improve and restore the quality of waters not presently meeting water quality standards." Policies include:

- Protect and use natural water systems in lieu of structural alternatives, and restore modified systems.
- Establish minimum seasonal flows and levels for surface waters to ensure protection of natural resources, especially marine, estuarine, and aquatic ecosystems.
- Discourage the channelization, diversion, or damming of natural riverine systems.
- Encourage the development of a strict floodplain management program to preserve hydrologically significant wetlands and other natural floodplain features.
- Protect surface and ground-water quality and quantity.
- Eliminate the discharge of inadequately treated wastewater and stormwater runoff into waters of the state.

Coastal/Marine Resources policies include:

- Accelerate public acquisition of coastal and beachfront land to protect coastal and marine resources.
- Avoid spending state funds that subsidize development in high-hazard coastal areas.
- Protect coastal and marine resources and dune systems from the adverse impacts of development.

For the Natural Systems and Recreational Lands Element, the goal is to protect and acquire unique natural habitats and ecosystems and to restore degraded natural systems. Policies include:

- Protect and restore the ecological functions of wetlands systems to ensure their long-term environmental, economic, and recreational value.
- Promote restoration of the Everglades system and of the hydrological and ecological functions of degraded or disrupted surface waters.
- Implement a comprehensive planning, management, and acquisition program to ensure the integrity of Florida's river systems.

Agriculture policies include:

- Eliminate the discharge of inadequately treated agricultural wastewater and stormwater runoff to surface waters.
- Conserve soil resources to prevent sedimentation of state waters.

Rule 9J-5 contains many minimum requirements for goals, objectives, and policies that are directly related to the conservation, protection, and proper use and management of natural resources. The following are some examples.

Public Facilities policies include:

- Correct existing facility deficiencies and coordinate the extension of, or increases in the capacity of, facilities to meet future needs.
- Maximize the use of existing facilities to discourage urban sprawl.

- Regulate land use and development to protect the functions of natural stormwater features and natural ground-water aquifer recharge areas.

Conservation policies include:

- Conserve, appropriately use, and protect the quantity and quality of water, minerals, soils, native vegetative communities, fisheries, wildlife, and wildlife habitat.
- Protect air quality, native vegetative communities, and water quality.
- Protection and conservation of the natural functions of soils, fisheries, wildlife habitats, surface waters, ground waters, and beaches and shorelines.

## Growth Management in Florida, Chapter 3

After several years of living with and implementing the 1985 growth management law, numerous issues were arising that suggested that the program needed fine tuning. On one side were people who thought that the program and process were hindering economic development, stepping on private property rights, and becoming cumbersome administratively. Others felt that the program was not adequately protecting social, economic, and environmental resources. In 1991, the third Environmental Land Management Study Committee (ELMS III) was formed to provide recommendations to the 1993 legislature on ways to further improve and refine Florida's growth management laws. The Committee's report included the following conclusion (5):

> Florida's growth management process is not in a state of disrepair, but it needs some immediate attention. More importantly, it needs executive leadership to protect the substantial investment that has been made so that it will not be lost, or worse, become a liability. Decisions that are made over the next 12 to 18 months will determine whether our efforts will be able to deliver the promises made. The tools for managing future growth and change are in place. The challenge is whether these tools and our leadership can respond when asked to perform.

The Committee's Final Report and Recommendations formed the basis for a new planning and growth management act which passed by overwhelming margins in both the house and the senate in the closing days of the 1993 session. Among the provisions of the 180-page law are some major changes relating to state planning, regional planning, the DRI process, local planning and concurrency, and infrastructure funding as explained below (6).

### *State Planning*

One of the biggest criticisms of Florida's growth management system is the lack of strong leadership at the state level. The State Comprehensive Plan originally was envisioned as a leadership document with strong, measurable, and strategic goals that would set a course for the state's growth and guide the development and implementation of state programs. State agency and program budgeting decisions, however, never were changed to incorporate the State Plan's requirements. Furthermore, key components of the State Plan—the capital plan and budget—never were developed or adopted. These omissions have resulted in a lack of a cohesive, integrated, comprehensive vision of Florida's future as well as a lack of financial resources to implement the program and to correct existing infrastructure deficiencies.

The 1993 Growth Management Act strengthens the state planning process in two ways. First, it requires the Governor's Office to review and analyze the State Comprehensive Plan biannually and submit a written report recommending revisions or explaining why no revisions are necessary. Second, the act requires that a new Growth Management Element be prepared and submitted to the 1994 legislature. The element must be strategic in nature; provide guidance for state, regional, and local actions necessary to implement the State Plan; identify metropolitan and urban growth centers; establish strategies to protect identified areas of state and regional environmental significance; and provide guidelines for determining where urban growth is appropriate and should be encouraged.

### *Regional Planning*

The 1993 Growth Management Act greatly changes the role and powers of the regional planning councils. The regional planning councils are charged with planning and coordinating intergovernmental solutions to multijurisdictional growth-related problems, with no regulatory authority. Regional policy plans will now be required to address only affordable housing, economic development, emergency preparedness, regionally significant natural resources, and regional transportation, and these plans will no longer be a basis for determining the consistency of local plans.

### *The DRI Process*

The act provides for the termination of the DRI process in large jurisdictions (counties greater than 100,000 population) when they adopt specific intergovernmental coordination mechanisms. The law also greatly revises the DRI process in those counties and cities that retain the process. Fewer projects will be considered DRIs, the regional planning councils will be allowed to address only state and regional resources or facilities, and the review process is expedited for projects that are consistent with the local comprehensive plan.

### *Local Planning*

The act makes several very substantial changes in the local planning process, especially with respect to the plan amendment review process, sanctions, intergovernmental coordination, and evaluation and appraisal reports. The plan amendment review process is streamlined, with DCA issuing an ORC Report for a proposed amendment only if a regional planning council, affected person, or local government requests it or if DCA decides to conduct such a review. All adopted plan amendments will be reviewed by DCA for compliance with state laws. The law greatly changes and strengthens the evaluation and review reporting requirements. The DCA is directed to adopt a rule establishing a phased schedule for the submittal of evaluation and appraisal reports no later than 6 years after local plan adoption and then every 5 years thereafter.

### *Concurrency and Infrastructure Funding*

The act codifies DCA's existing concurrency management rule and policies, thereby providing specific legislative guidance on this critical component of the planning process. To avoid conflicts with other state planning goals, the act authorizes local governments to provide an exception from transportation concurrency requirements in areas designated for urban in-fill development, urban redevelopment areas, existing urban service areas, or certain downtown revitalization areas. The act authorizes local governments to adopt a "pay and go" system for transportation concurrency if the local plan includes a financially feasible capital improvement plan to upgrade transportation facilities and establishes an impact fee or other system requiring the developer to pay its fair share of needed transportation facilities. Unfortunately, while ELMS III recommended a 10-cent statewide gas tax increase to provide infrastructure funding, the legislature only authorized local governments to increase the local option gas tax by up to 5 cents.

## Recommendations

Based on experience with Florida's growth management programs over the past 15 years, the following recommendations are made to streamline the process and enhance protection of Florida's natural resources.

The program and its requirements must recognize the inherently different growth management needs of highly urbanized areas or rapidly growing areas and separate them from the planning needs of rural areas, especially those with very slow growth rates. Flexibility, with consistency, is the key.

Rural local governments, especially in those areas experiencing growth, have the most to gain from comprehensive planning. Hopefully, they can avoid the mistakes that have been made in central and southern Florida where unplanned growth adversely affected social, economic, and environmental resources. Rural local governments, however, need extensive technical assistance and funding to develop and implement sound comprehensive plans.

Probably the greatest hindrance to solving Florida's existing growth management problems and preventing future growth from exacerbating them is the implementation, at both state and local levels, of dedicated funding sources. At the state level, the Growth Management Program, the Surface Water Improvement and Management Program, the State Stormwater Demonstration Grant Program, and the Preservation 2000 Land Acquisition Program are underfunded and depend on annual legislative appropriations. Dedicated funding sources such as increases in documentary stamp taxes or the placement of small fees on products such as concrete, asphalt, fertilizer, pesticides, and water use or even electric bills could generate sufficient funding levels to ensure that these programs succeed. At the local level, impact fees, gasoline taxes, and the establishment of stormwater utilities (already implemented by over 50 local governments) are essential if funds sufficient to pay for needed infrastructure improvements are to be raised.

The state's land planning and water planning frameworks need to be better integrated. In particular, the Department of Environmental Regulation and the five regional water management districts need to be the lead agencies involved with water management issues. Greater consistency and integration is needed between local comprehensive plans and requirements set forth in State Water Policy, Chapter 17-40, FAC. Currently, local comprehensive plans only are required to "consider" State Water Policy rather than to be "consistent with."

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# *Stormwater and the Clean Water Act: Municipal Separate Storm Sewers in the Moratorium*

**Kevin Weiss**
**Office of Wastewater Enforcement and Compliance, Office of Water, U.S. Environmental Protection Agency, Washington, DC**

## Abstract

Urban stormwater and related pollutant sources have been shown to be major sources of water quality impairment. Section 402(p)(6) of the Clean Water Act requires the U.S. Environmental Protection Agency to identify additional stormwater sources to be regulated to protect water quality under Phase II of the National Pollutant Discharge Elimination System (NPDES) program. Mitigating water quality impairment associated with urban runoff requires comprehensive efforts with special emphasis on comprehensive approaches to stormwater management for new development. Municipal governments in urbanized areas appear to be critical institutions for making many of the day-to-day decisions necessary to address problems associated with stormwater, including measures to minimize the risks to water resources associated with stormwater from areas undergoing urbanization. In addition, municipalities have the police power needed to implement some components of stormwater programs and the ability to collect funds to be used in program implementation. This paper looks at the use of NPDES permits for discharges from municipal separate storm sewers systems in urbanized areas as a tool for defining the federal/state/municipal relationship for addressing stormwater management.

## Environmental Background

Urban stormwater discharges have been shown to be a major cause of impairment of surface water resources. The *National Water Quality Inventory 1990 Report to Congress* provides a general assessment of surface water quality based on biennial reports submitted by the states under Section 305(b) of the Clean Water Act (CWA). The report indicates that of the rivers, lakes, and estuaries that the states assessed, roughly 60 to 70 percent are supporting the uses for which they were designated. Urban lands, however, only account for 2 percent of lands in the United States (1). The report indicates that urban runoff is a major source of impairment for 53 percent of impaired estuary acres, 36 percent of impaired ocean coastal miles, 29 percent of impaired lake acres, 6 percent of impaired Great Lake shoreline, and 9.6 percent of impaired river miles. The report also indicates that combined sewer overflows, which are a mixture of urban runoff, sanitary sewage, and industrial process discharges, are sources of impairment for 4 percent of impaired estuary acres, 3.6 percent of impaired ocean coastal miles, 7.5 percent of impaired Great Lakes shoreline, and 2.8 percent of impaired river miles. Urban runoff affects receiving waters in or near urban population centers and therefore may limit the uses and values of the waters closest to the most people.

Surface water resources are affected by two characteristics of urban runoff: 1) elevated pollution concentrations and loadings and 2) changes in flow patterns that accompany urbanization. The nature of the receiving water determines whether increased pollutant loadings or changes to natural flow patterns or a combination of both are causes of impairment. For example, slower moving rivers, streams, lakes, and estuaries can be more sensitive to increased pollutant loadings than to changes in flow patterns. Conversely, faster moving streams, such as those found in hilly or mountainous areas, can flush pollutants but may be sensitive to dramatic changes in flow patterns. A good comparison of these impacts is provided by Pitt, who compares impacts in Coyote Creek (San Jose, California), a stream with relatively slow flows, with impacts in Kelsey and Bear Creeks (Bellevue, Washington), streams with high flows and good flushing capabilities (2, 3).

## Sources of Pollutants in Urban Stormwater

Pollutants discharged from municipal separate storm sewer systems originate from a variety of diffuse sources. EPA has identified four major classes of sources that contribute pollutants to discharges from municipal separate storm sewer systems (4):

- Nonstormwater sources
- Residential and commercial sources
- Industrial sources
- Construction activities

### *Nonstormwater Sources*

Although separate storm sewers are primarily designed to remove runoff from storm events, materials other than stormwater find their way into and are ultimately discharged from separate storm sewers. For example, in Sacramento, California, less than half the water discharged from the stormwater drainage system was directly attributed to precipitation (5). Nonstormwater discharges to storm sewers come from a variety of sources, including:

- Illicit connections and cross connections from industrial, commercial, and sanitary sewage sources.
- Improper disposal of wastes, wastewaters, and litter.
- Spills.
- Leaking sanitary sewage systems.
- Malfunctioning septic tanks.
- Infiltration of ground water contaminated by a variety of sources including leaking underground storage tanks.
- Wash waters, lawn irrigation, and other drainage sources.

For a more complete description of nonstormwater discharges to storm sewers, see U.S. EPA (6).

Table 1 provides a summary of several studies involving problems with nonstormwater discharges. These case studies illustrate the wide range of pollutants that can enter storm sewers from nonstormwater discharges,

**Table 1. Summary of Nonstormwater Discharge Problems**

| Study Site | Comments |
|---|---|
| Jones Falls Watershed, Baltimore City and County, MD | During the NURP study of the Jones Falls Watershed, 15 illicit connections were discovered in portions of the watershed. The illicit connections were grouped into four types: direct discharges from residences; leakage from cracked or broken sewer lines; decades-old overflows from the sanitary sewer; and sanitary sewage pumping station malfunctions. Elevated levels of pathogens, TSS, ammonia, TKN, total nitrogen, COD, and TOC were identified. |
| Tulsa, OK | A physical inspection was conducted of 120,000 ft of storm sewer 48 in. and larger serving a drainage area of approximately 12 square miles. Thirty-five potential nonstormwater discharges were observed. Twenty-three of these were observed and/or suspected sanitary sewer connections, four were potable water discharges, and eight were of unknown origin. In addition, 12,900 ft of sanitary sewer was laid within the storm sewer, where the storm sewer served as a conduit. Most illicit connections were associated with development that occurred before 1970. Other documented observations were structural defects (900 ft of pipe showed signs of structural defects), pipe cross through (176 total), and debris buildup. |
| Washtenaw County, MI | Inspection of 1,067 businesses, homes, and other buildings was conducted, with 154 of the buildings (14%) identified as having illicit connections, including connections in restaurants, dormitories, car washes, and auto repair facilities. About 60% of the automobile-related businesses inspected had illicit discharges. A majority of the illicit connections discovered had been approved connections when installed. Pollutants that were detected included heavy metals, nutrients, TSS, oil and grease, radiator fluids, and solvents. |
| Fort Worth, TX | Twenty-four outfalls in a 10-mile radius were targeted for end-of-pipe observations. The success of the program was judged by a decline in the number of undesirable features at the target outfalls from an average of 44 undesirable observations per month in 1986 (522 total) to an average of 21 undesirable observations per month in 1988. The Fort Worth investigation indicated problems associated with allowing septic tanks, self-management of liquid waste by industry, and construction of municipal overflow bypasses from the sanitary sewer to the storm drains. These problems were attributed to the inability of the publicly owned treatment works to expand as rapidly as urban growth occurred. During a 30-month period, problems detected included 133 hazardous spills, 125 incidents related to industrial activity, 265 sanitary sewer line breaks, and 21 bypass connections of the sanitary sewer to the storm sewer. Highlighted cases included a 20-gal/min flow from a cracked sanitary sewer from a bean processing plant to a storm drain and an illicit connection of a sanitary sewer line from a 12-story office building to a storm sewer. Most industrial pollution enters the storm sewer system from illegal dumping, storm runoff, accidental spills, and direct discharges. Metals were not detected in dry-weather discharges but were found in significant levels in receiving water sediment. City officials state that the high metal concentrations in sediment are consistent with otherwise unexplained serious reported fish kills. |

**Table 1. Summary of Nonstormwater Discharge Problems**

| Study Site | Comments |
|---|---|
| Seattle, WA | The city of Seattle has detected improper disposal and illicit connections from industrial sites by investigating sediment in storm sewers. One storm drain outfall representing a major source of lead to the Duwamish River was traced back to a former smelter that crushed batteries to recover lead. Lead concentrations in the sediment were high enough to allow the city to send it to an operating smelter to be refined. Another storm drain contained high levels of creosote, pentachlorophenol, copper, arsenic, and PCBs, which (except for the PCBs) were traced back to a wood treatment facility. Contaminated sediments removed from the storm drain (30 $yd^3$) contained 145 lb of contaminants. Sediments removed from storm drains in another industrial area contained very high levels of PCBs (about 1 lb PCBs/70 $yd^3$ sediment). |
| Upper Mystic Lake, NY | The NURP study for the Mystic Lake Watershed project identified contamination of stormwater runoff and subsequently surface water contamination of surface waters by sanitary discharges as a major problem in the watershed that contributed large quantities of phosphorus, certain metals, and bacteria. Interactions at 19 manholes that served both sanitary and storm sewer lines were identified as the major contributor of pollutants. |
| Bellevue, WA | The NURP report for Bellevue recorded 50 voluntary citizen reports of illegal dumping and other nonstormwater discharges during a 27-month period. The incidents reported were varied and resulted in at least two significant fish kills. Of the citizen reports, 25% involved improper disposal of used oil to the storm sewer. Other reports involved spills; illicit connections of floor drains, septic tank pipes, and a car wash; chemical dumping; and concrete trucks rinsing out into catchbasins or streams. |
| Ann Arbor, MI | Studies in 1963, 1978, and 1979 found that discharges from the Allen Creek storm drain contained significant quantities of fecal coliform, fecal streptococci, solids, nitrates, and metals. Of the 160 businesses dye-tested, 61 (38%) were found to have improper storm drain connections. Chemical pollutants including detergents, oil, grease, radiator wastes, and solvents were causing water quality problems. Monitoring of the storm drainage system during storm events indicated a decrease in the concentration of 32 of 37 chemicals monitored after the improper connections were removed. |
| Medford, OR | Fecal coliform tests at storm drain outfalls in city parks were used to detect four leaking sewer lines, which either were located above the storm lines or saturated the ground with effluent, which entered the nearby storm drains, an agricultural equipment wash rack, and a house with sanitary lines plumbed to the storm drain. In addition, in one of the oldest sections of town a large storm drain bored in the early 1900s also contained the sanitary sewer line. Under manholes, the sanitary line was only a trough. Even minor clogs or breaks resulted in a spillover of effluent in the storm drain below. |
| Toronto, Ontario | Dry weather sampling of discharges from 625 storm drains in the Humber River Watershed. About 10% of the outfalls were considered significant sources of nutrients, phenols, and/or metals, while 30 of the outfalls had fecal coliform levels >10,000/100 mL. Investigations identified 93 industrial and sanitary sewage illicit connections. Problems included residential connections of sanitary sewage to the storm sewers and yard runoff from a meat packing plant to a storm drain. |
| Grays Harbor, WA | Dry weather sampling of 29 outfalls of separate storm drains indicated that discharges from six of the outfalls had abnormally high pollutant levels with suspected illicit connections. The area under consideration had originally been served by combined sewers. Earlier efforts to separate the system had been incomplete, with some residences discharging sanitary sewage to the storm drain. |
| Seward, NY | Sewage from septic tanks with clogged drainfields in clay soils flowed into open storm sewers. The open storm sewers posed health risks to neighborhood children and lowered property values. |
| Norfolk Naval Station, VA | The Norfolk Naval Shipyard was originally built in 1767 and has had numerous additions since that time. It has an extensive network of underground pipes that includes both separate storm sewers and sanitary/industrial sewers. In response to a lawsuit, officials at the shipyard conducted dye-testing of sanitary facilities throughout the shipyard, which led to the identification and elimination of 25 cross connections of sanitary and industrial waste to the separate storm sewer system. |
| Sacramento, CA | The city of Sacramento is currently undertaking a project to identify pollutant discharges and illegal connections into the stormwater drainage systems. Recent studies identified acute toxicity in stormwater, and revealed that less than half the water discharged from the drainage system was not directly attributable to precipitation. Mass loading estimates of copper, lead, and zinc discharged by the drainage system were several times higher than the estimated pollutant loads of these metals from the Sacramento Regional Treatment Plan secondary effluent. |
| Hazardous waste case studies | Cases of onsite waste disposal where pollutants were added to runoff that eventually ended up in drainage systems and other cases where a generator dumped wastes directly down a drain were common. Of the 36 cases of illegal dumping investigated in a GAO report, 14 cases investigated involved disposal of hazardous waste directly to, or with drainage to, a storm sewer, flood control structure, or the side of a road. An additional 10 sites involved disposal to the ground, landfills (other than those receiving hazardous wastes), and trash bins, which can then result in added pollutants to subsequent stormwater discharges. |

including pathogens, metals, nutrients, oil and grease, metals, phenols, and solvents. Removal of these non-stormwater pollutant sources often provides opportunities for dramatic improvement in the quality of discharges from separate storm sewers.

### Residential and Commercial Runoff

Residential and commercial activities are the predominate land uses in most urbanized areas (UAs), typically occupying between 55 to 85 percent of the total area. Major pollutants associated with residential and commercial runoff include heavy metals, oxygen demanding materials, bacteria, nutrients, floatables, organics, pesticides, polynuclear aromatic hydrocarbons (PAHs), and other toxic organic pollutants.

From 1978 through 1983, the U.S. Environmental Protection Agency (EPA) provided funding and guidance to the Nationwide Urban Runoff Program (NURP) to study the nature of runoff from commercial and residential areas. The NURP study provides insight into what can be considered background levels of pollutants in runoff from residential and commercial land uses. Sites used in the NURP study were carefully selected so that they were not affected by pollutant contributions from construction sites, industrial activities, or illicit connections. Data from several sites had to be eliminated from the study because of elevated pollutant loads associated with these sources.

Data collected in NURP indicated that on an annual loadings basis, suspended solids in discharges from separate storm sewers draining runoff from residential and commercial areas are approximately an order of magnitude or more greater than in effluent from sewage treatment plants receiving secondary treatment. In addition, the study indicated that annual loadings of chemical oxygen demand (COD) is comparable in magnitude with effluent from sewage treatment plants receiving secondary treatment.

Table 2 compares annual pollutant loadings for three metals—zinc, lead, and copper—from urban runoff from the Metropolitan Washington UA, from a sewage treatment plant that provides advanced treatment and that serves about 2 million people (the Blue Plains sewage treatment plant), and from major industrial process wastewater discharges located in Maryland and Virginia.

When analyzing annual loadings associated with urban runoff, it is important to recognize that discharges of urban runoff are highly intermittent, and that the short-term loadings associated with individual events will be high and may have shockloading effects on receiving water.

Pollutant loadings for urban stormwater are based on the "Simple Method" developed by the Washington Metropolitan Council of Governments (7). Pollutant concentrations used in this model were based on those published in U.S. EPA (8). The values for lead were reduced by 75 percent to account for assumed reductions due to reductions in the use of lead in gasoline.

Pollutant loadings for direct dischargers in the Toxics Release Inventory are as reported in Cameron (9). The Toxics Release Inventory contains data on toxic chemical releases by industrial facilities that use 10,000 lb or more of specified toxic chemicals and does not include all releases from all industrial facilities in a state.

### Industrial Runoff

A number of studies indicate that runoff from industrial land uses has relatively poorer water quality than other general land uses (8, 10-13). In general, a greater variety and larger amounts of toxic materials can be used, produced, stored, or transported in industrial areas. Industrial activities that can provide a significant source of pollutants to stormwater from industrial sites include loading and unloading, outdoor storage, outdoor processes, illicit connections or management practices, and waste disposal practices. In addition, many heavy industrial areas have a large degree of imperviousness, which results in high volumes of runoff. Atmospheric deposition and spills and leaks associated with material transport can contribute to significant levels of toxic constituents in runoff to areas surrounding or in close proximity to heavy industrial activity.

**Table 2. Annual Pollutant Loadings (in Pounds) in Stormwater From Selected Pollutant Sources**

| Pollutant | Urban Stormwater From Metropolitan Washington | Blue Plains POTW[a] | All MD and VA Direct Industrial Discharges in 1987 Toxic Release Inventory |
|---|---|---|---|
| Zinc | 480,000 | 137,000 | 132,000 |
| Lead | 132,600 | 5,500 | 31,300 |
| Copper | 113,000 | 21,000 | 127,000 |
| Nitrogen | 30,000,000 | 12,000,000 | Not available |
| Phosphorus | 1,200,000 | 113,000 | Not available |
| BOD5 | 9,500,000 | 1,400,000 | Not available |

[a]Blue Plains POTW loadings estimates based on EPA Permit Compliance System (PCS) data for 1989.

### *Runoff From Construction Activities*

The amount of sediment in stormwater discharges from construction sites can vary considerably, depending on whether the discharges are uncontrolled or whether effective management practices are implemented at the construction site. Sediment loads from uncontrolled or inadequately controlled construction sites have been reported to be on the order of 35 to 45 tons/acre/year. Sediment loads from uncontrolled construction sites are typically 10 to 20 times that of agricultural lands, with sediment loads as high as 100 times that of agricultural lands and typically 1,000 to 2,000 times that of forest lands. Over a short period, construction sites can contribute more sediment to streams than was previously deposited over several decades.

## Changes to Flow Patterns: Physical Impacts

Urbanization can result in dramatic changes to the natural flow patterns of urban streams and wetlands. In undeveloped watersheds, most rainfall infiltrates into the ground and recharges ground-water supplies. Urbanization alters the natural vegetation and natural infiltration characteristics of a watershed, which results in much higher peak flows and reduced base flows in urban streams. Increased peak flows can result in stream bank erosion, streambed scour, flooding, channelization, and elimination or alteration of habitat (14). Increases in peak flows can also create the need to modify stream channels through a variety of engineered structures, such as retaining walls, rip-rap, and channel dredging.

Increased imperviousness and loss of wetlands and natural flow channels also decrease the amount of rainwater available for ground-water recharge. Reduced ground water levels reduce base flows in streams during dry weather periods, which impairs the aquatic habitat, impairs riparian wetlands, and makes receiving streams more sensitive to other pollutant inputs and sedimentation.

## Development Patterns

In the United States, population patterns typically do not follow the political boundaries of municipalities. Prior to 1950, many large core cities annexed additional fringe areas as populations of the urban center increased. The trend of core cities increasing in area through annexation has largely stopped in most major UAs. In most states, smaller "suburban" local governments surrounding the core city are retained or created.[1] Thus, today most urban centers are composed of a large core city surrounded by several smaller "suburban" municipalities.

Every 10 years, the Bureau of Census defines UAs to characterize the population and development patterns of large urban centers of 50,000 or more. UAs are composed of a central city (or cities) with a surrounding closely settled area. The population of the entire UA must be greater than 50,000 persons. The closely settled area outside of the city, the urban fringe, must have a population density generally greater than 1,000 persons per square mile (just over 1.5 persons per acre) to be included. The boundaries of UAs are based on population patterns, not political boundaries; therefore, they do not include significant portions of rural land.

The Bureau of Census has defined 396 UAs in the United States based on the 1990 Census. These UAs have a combined population of 158.3 million, or 63.6 percent of the nation's total population;[2] however, these areas only account for 1.5 to 2 percent of the land surface of the country. Most increases in population occur in urban fringe or suburban municipalities rather than in core cities.[3]

## Clean Water Act Requirements

In 1972, the CWA was amended to provide that the discharge of any pollutants to waters of the United States from a point source is unlawful, except where the discharge is authorized by an NPDES permit. The term "point source" is broadly defined to include "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, [or] channel, . . . from which pollutants are or may be discharged." (Congress has specifically exempted agricultural stormwater discharges and return flows from irrigated agriculture from the definition of point source.) Although the definition of point source is very broad, prior to 1987, efforts under the NPDES program to control water pollution have focused on controlling pollutants in discharges from

[1]The patterns and functions of local governments in suburban fringe areas vary from state to state. In some states, such as Maryland, Virginia, Florida, and California, and, to a lesser degree, a number of southern states and Texas, large urban populations outside of core cities are in unincorporated portions of counties. In these cases, the county government conducts the major functions of local government. However, in most States, including New England, mid-Atlantic, Great Lake, midwestern, and most western states, the primary form of local government for many municipal functions is not a county but either an incorporated place or a minor civil division. (These terms are defined in Table 3.)

[2]The Census Bureau defines urban populations more broadly than UAs. Urban populations include the populations of UAs and any other dense population of 2,500 or more people. The 1990 Census indicates that 28.8 million people who lived outside of UAs were classed as urban populations. The Bureau of Census classified populations that are not classified as urban (including UAs) as rural. The 1990 Census indicates that 61.6 million people were classified as living in rural areas.

[3]The 1990 Census indicates that the total population of the United States increased by 22.1 million between 1980 and 1990. Of this growth, 86 percent (19 million) was in Census-designated UAs. Cities with a population of 100,000 or more accounted for 22 percent of this growth (4.9 million), while suburban areas surrounding these areas grew by 11.5 million (52 percent of the national total). Another 12 percent of the national growth (2.6 million) occurred in UAs that did not have a core city of 100,000 or more.

publicly owned treatment works (POTWs) and industrial process wastewaters. The major exception to this are the 10 effluent limitation guidelines that EPA has issued for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

As part of the Water Quality Act of 1987, Congress added Section 402(p) to the CWA to require EPA to develop a comprehensive, phased program for regulated stormwater discharges under the NPDES program. Under the first phase of the post-1987 program, EPA is to develop requirements for:

- Stormwater discharges associated with industrial activity.
- Discharges from large municipal separate storm sewer systems (systems serving a population of 250,000 or more) and medium municipal separate storm sewer systems (systems serving a population of 100,000 to 250,000).
- Discharges that are designated by EPA or an NPDES-approved state as needing an NPDES permit because the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

Section 402(p)(1) of the CWA creates a temporary moratorium on the requirement that point source discharges of pollutants to U.S. waters must be authorized by an NPDES permit for other stormwater discharges.[4] Under the moratorium, EPA is prohibited from issuing NPDES permits for discharges composed entirely of stormwater that are not specifically exempted from the moratorium (the discharges listed above to be addressed during the first phase of the program) prior to October 1, 1994.[5] Before this time, EPA, in consultation with the states, is required to conduct two studies on stormwater discharges. The first study is to identify those stormwater discharges or classes of stormwater discharges for which permits are not required prior to October 1, 1994, and to determine, to the maximum extent practicable, the nature and extent of pollutants in such discharges. The second study is to establish procedures and methods to control stormwater discharges to the extent necessary to mitigate impacts on water quality.

Based on the two studies, EPA is required to issue regulations by no later than October 1, 1993, that designate additional stormwater discharges to be regulated to protect water quality and establish a comprehensive program to regulate such designated sources. The program must, at a minimum:

- Establish priorities.
- Establish requirements for state stormwater management programs.
- Establish expeditious deadlines.

The program may include performance standards, guidelines, guidance, management practices, and treatment requirements, as appropriate.

The 1987 amendments to the CWA made significant changes to the permit requirements for discharges from municipal separate storm sewers. Section 402(p)(3)(B) of the CWA provides that NPDES permits for such discharges:

- May be issued on a system- or jurisdictionwide basis.
- Shall include a requirement to effectively prohibit nonstormwater discharges into storm sewers.
- Shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Director determines appropriate for the control of such pollutants.

## Initial Implementation

On November 16, 1990, EPA published the initial NPDES regulations under Section 402(p) of the CWA (see 55 FR 47990). The November 16, 1990, regulations:

- Defined the initial scope of the program by defining the terms "stormwater discharge associated with industrial activity" and large and medium "municipal separate storm sewer systems."
- Established permit application requirements.
- Established deadlines.

The regulatory definitions of large and medium municipal separate storm sewer systems specifically identified 173 incorporated cities and 47 counties, and allowed for additional designations of adjacent municipalities on a case-by-case basis. EPA estimates that 400 additional municipalities with a combined population of about 16 million people have been designated by EPA and authorized NPDES states, and that 23 cities with a population of 100,000 or more (and a combined population of 8.6 million people) have been excluded from stormwater

[4]The Conference Report for the 1987 amendments to the CWA provides that after the moratorium ends on October 1, 1994, "*all* municipal separate storm sewers are subject to the requirements of Sections 301 and 402" (emphasis added) (15).

[5]The 1987 amendments to the CWA originally provided that the moratorium on other stormwater discharges (Water Resources Development Act) expire on October 1, 1992. Under the amendments, EPA was required to issue additional regulations to address these sources.

requirements due to large populations served by combined sewer systems.

The November 16, 1990, regulations were based on 1980 Census data. Data from the 1990 Census indicates that 30 additional cities have a population of more than 100,000, and five of the cities listed in the November 16, 1990, regulations no longer have a population of 100,000 or more. In addition, the 1990 Census indicates that 12 additional counties have an unincorporated, urbanized population of 100,000, and two counties listed in the November 16, 1990, regulations no longer have an unincorporated, urbanized population of 100,000.

The November 16, 1990, regulations also established requirements for a comprehensive, two-part permit application for discharges from large and medium municipal separate storm sewer systems. The major objectives of the permit application requirements are to ensure that municipalities develop comprehensive municipal stormwater management programs that address water quality, and to begin to implement these programs.

The permit application requirements for discharges from municipal separate storm sewer systems represent a new approach to addressing pollutant sources under the NPDES program. NPDES permit application requirements for other types of discharges traditionally focused on sampling end-of-pipe discharges. Permit applications for discharges from municipal separate storm sewer systems place a lesser emphasis on discharge sampling for a number of reasons, including the large number of discharge points commonly associated with municipal systems and the recognition that many municipalities were only initiating efforts to reduce pollutants in stormwater discharges at the time (see 55 FR 47990). Municipalities are required to submit comprehensive applications providing information that: 1) identifies major sources of pollution to the system, 2) characterizes pollutants in system discharges, 3) describes existing and proposed municipal stormwater management programs, and 4) describes the administrative and legal aspects of the municipal stormwater management program.

Perhaps the most important aspect of the permit application requirements is that they lay out the framework for municipalities to propose comprehensive municipal stormwater management programs. When developing permit conditions, permit writers will consider the management programs that are proposed as part of the permit applications. The municipal stormwater management programs envisioned by the November 16, 1990, regulations address the four following areas:

- *Measures to reduce pollutants in runoff from residential and commercial areas:* A major focus of this program component is controlling pollutants in stormwater from new development where stormwater controls are generally more cost effective and municipalities do not have to incur costs directly. Retrofitting controls for existing development can also be considered where practicable. Another focus is vegetation maintenance and snow removal activities for roads. Other source control measures, such as transportation plans, can be required where practicable.
- *Measures to reduce pollutants in runoff from industrial facilities:* EPA anticipates that a large percentage of stormwater discharges associated with industrial activity discharge through municipal separate storm sewer systems. The Agency intends to coordinate requirements in permits for stormwater discharges associated with industrial activity with efforts to develop municipal stormwater management programs in permits for discharges from municipal separate storm sewer systems serving a population of 100,000 or more. Under this coordinated effort, municipal permittees will have a major role in implementing programs to control pollutants from stormwater associated with industrial activity that discharges through their municipal separate storm sewers. For example, municipal operators can assist EPA and authorized NPDES states in identifying priority stormwater discharges associated with industrial activity; reviewing and evaluating stormwater pollution prevention plans developed by industrial facilities pursuant to NPDES permit requirements; and complying with requirements. (See 56 FR 40972 for a more complete description of the relationship EPA intends to develop between federal, state, and local governments for controlling pollutants in stormwater from industrial sources.)
- *Measures to reduce pollutants in runoff from construction sites:* Many municipalities currently have sediment and erosion requirements for construction activities. These programs, however, often are not adequately implemented or enforced. NPDES permit conditions for municipalities are expected to focus on ensuring adequate municipal implementation and enforcement of their controls. (See 57 FR 41206 and Metropolitan Washington Council of Governments [17].)
- *Measures to detect and control nonstormwater discharges to the storm sewer system:* Nonstormwater discharges to separate storm sewer systems are a major pollutant source in many municipalities. EPA anticipates that permits will require municipalities to continue field screening efforts started during the permit application phase of the program and to undertake other efforts to detect and control nonstormwater discharges.

For a more complete description of the components of a municipal stormwater management program, see *Guidance Manual for the Preparation of Part 2 of the*

*NPDES Permit Applications for Discharges From Municipal Separate Storm Sewer Systems* (16).

The November 16, 1990, regulations take two very different approaches to defining the roles of different levels of government. With respect to permits for large and medium municipal systems, the efforts of the NPDES permit authority (EPA or an authorized NPDES state) are directed toward ensuring that municipalities develop and implement stormwater management programs to control pollutants to the maximum extent practicable. Under these requirements, the NPDES program can define the role of municipalities in a flexible manner that allows local governments to assist in identifying priority pollutant sources within the municipality and to develop and implement appropriate controls for such discharges. With respect to permits for stormwater discharges associated with industrial activity, the NPDES permit authority has a direct role in regulating individual industrial sites.

## Moratorium Sources: Why Municipalities?

Section 402(p)(6) of the CWA requires EPA to issue regulations that designate additional stormwater discharges to be regulated to protect water quality and that establish a comprehensive program to regulate such designated sources. EPA can generally take two different approaches to identifying classes of discharges to be regulated by NPDES permits: 1) to require municipalities to develop systemwide stormwater management programs, or 2) to require NPDES permit coverage for targeted commercial and residential facilities. When evaluating whether to address selected municipalities in the regulatory program required under Section 402(p)(6), the following factors should be considered:

- There are institutional considerations.
- Some existing municipal functions can be modified to address stormwater concerns in a cost-effective manner.
- Municipal participation is necessary for regional or systemwide stormwater management programs.
- There are pollutant load considerations.
- Issuing permits to municipalities allows for municipal programs that incorporate innovative controls, such as market-based incentives and pollutant trading.
- Municipalities are in the best position to address high risk sources, including new development, and to protect priority resources and watersheds.
- Some municipal activities are significant pollutant sources.
- Municipalities can ensure maintenance of structural controls and implementation of nonstructural measures.

### *Institutional Considerations*

Municipalities contain the institutions that are critical for surface water resource protection programs. Urban stormwater management has been, is, and will continue to be primarily the responsibility of local governments (18). Municipalities install or oversee the installation of storm sewer systems to provide drainage for lands used for residential, commercial, and industrial activities as well as roads and highways. Municipalities can provide the institutional framework necessary to implement many components of an effective stormwater management program.

Components of a comprehensive stormwater management program that only municipalities can effectively address include land use planning, detailed oversight of new development, maintenance of roads, retrofitting controls in areas of existing development, and operation and maintenance of municipal storm drains. Municipalities can provide the detailed planning necessary to implement watershed and other risk-based approaches.

The role of municipalities under the NPDES program is to make stormwater management programs work. This involves overseeing day-to-day program operations, identifying local priorities and pollutant sources, developing detailed program requirements, conducting site inspections and evaluations, monitoring activities, assessing impacts to surface water resources, initiating compliance efforts, and ensuring effective outreach. Municipal activities can be funded by a variety of mechanisms, including general revenues, developer fees, flood control assessments, and stormwater utilities. Raising funds at the municipal level can provide a municipalitywide source of funds that can then be directed at priority projects. Thus, comprehensive programs can be implemented in a phased manner over a long period. In addition, such an approach takes advantage of pollutant trading concepts by directing resources from many sources to priority sources.

The role of the federal government and authorized NPDES states under the NPDES municipal stormwater program is to ensure that regulated entities implement pollution control measures. In the municipal stormwater area, this means providing oversight to guide the direction of municipal programs and providing technical assistance. Oversight activities include issuing permits that establish the framework for municipal stormwater control programs and taking targeted enforcement actions, for example, when municipalities fail to develop and implement a program. In addition, the NPDES authority must work in partnership with municipalities to ensure that, where appropriate, priority pollutant sources that municipalities may have difficulty controlling, such as certain federal or state facilities, are directly issued NPDES permits for their stormwater discharges. As Thomas Mumley, Associate Water Resource Control

Engineer at the San Francisco Regional Water Quality Control Board (19) states:

> Successful control of urban runoff will require a carrot, a stick, and . . . the implementation of common-sense, cost-effective, environmentally beneficial measures. . . . We need incentives to change our ways . . . we now have a big stick to drive these needed efforts, in the form of the NPDES stormwater regulations [for municipalities] which require the implementation of these measures. Fortunately, the current regulations promote flexibility[6] and don't impose a lot of bureaucratic red tape, and therein lies the carrot.

### *Expanding the Mission of Existing Municipal Programs*

Municipalities typically operate programs whose primary mission is to address a set of concerns other than stormwater or water quality. Expansion of the mission of these existing municipal programs to address stormwater concerns can be much more cost effective than initiating entirely new programs. Municipal functions that can be adapted to assist in providing stormwater management benefits include oversight of new development, pretreatment program implementation, fire safety inspections, flood control, trash collection, management of municipal lands, and road maintenance. Municipal lands, for example, can provide retrofit opportunities for a number of reasons. The use of municipal lands for retrofits typically does not require additional property purchases. In addition, the use of municipal lands ensures opportunities to provide future maintenance and security in preservation of the retrofit control. (See Washington State Department of Ecology [20] for special stormwater management practices for public buildings and streets; vehicle and equipment maintenance shops; maintenance of open space areas; maintenance of public stormwater facilities; maintenance of roadside vegetation and ditches; maintenance of public utility corridors; water and sewer districts and departments; and port districts.)

In addition, many municipal activities and programs can be significant sources of pollutants, such as road maintenance, road construction, siting and operating flood control devices, maintenance of municipal vehicles, municipal landfills, and airports.[7] Expanding the mission of these programs can assist in the development of a pervasive municipal ethic regarding stormwater management that ensures effective use of municipal resources and mitigates the effects of municipal activities that can affect water resources.

### *Regional or Systemwide Programs*

Urban stormwater is a diffuse source of pollution. The impacts of stormwater on receiving waters generally cannot be attributed to individual sources or discharge points; rather, the cumulative effects of many discharges from widespread areas of urban development in a watershed are of major concern. Often, approaches that consider watershed characteristics are necessary for success.

Control of urban stormwater is critical from a regional perspective, which addresses the entire UA. The lack of regional or systemwide planning is often cited as a major reason for incomplete and unsuccessful stormwater control efforts and for the inability to protect downstream areas from stormwater from upstream development. A comprehensive stormwater management program cannot rely solely on addressing individual sources within large UAs.

A regional approach can also bring together financial resources, planning, and scientific expertise not otherwise available for individual municipalities, thereby increasing the likelihood for success. Regional entities that can play an important role in planning, implementing, and evaluating stormwater programs include flood control districts, stormwater or drainage districts, counties, and Councils of Governments.

### *Pollutant Load Considerations*

UAs comprise a mixture of different land uses. For general planning purposes, most UAs are distributed as follows: residential, 50 to 70 percent; commercial, 10 to 20 percent; industrial, 10 to 15 percent; open area, 10 to 15 percent (13). Concentrations of pollutants in stormwater from nonindustrial areas can be assumed to be roughly the same for different land use types, but the degree of imperviousness plays an important role in determining pollutant loads (8). This is because many diffuse sources of pollutants to urban stormwater operate in different land use areas, and areawide sources are important. While commercial and industrial land uses generally have a higher level of imperviousness than some types of residential development, a large amount of residential area will result in residential land use being a major pollutant source to stormwater. For example, a study of the Santa Clara Valley found that the volume of stormwater flows from residential and

[6]Concerns have been raised regarding the requirements under the current Clean Water Act that NPDES permits for municipal separate storm sewers, in addition to mandating the reduction of pollutants to the maximum extent practicable, must ensure compliance with water quality standards. The water quality standards issue is not discussed in this paper.

[7]Some municipal activities are considered to be industrial activities under the NPDES program. Section 1068 of the Intermodial Surface Transportation Efficiency Act of 1991 placed stormwater discharges associated with industrial activity owned or operated by a municipality with a population of less than 100,000 in the moratorium from NPDES permit requirements.

commercial land uses in the Valley was 10 times greater than the volume of flow from industrial uses. The loading of metals in stormwater flows from residential and commercial lands was estimated to be 5 to 30 times greater than from industrial lands (11).

A program that only addresses industrial stormwater flows is limited because it only addresses a fraction of the total urban stormwater flows. Similarly, programs to address illicit connections to storm sewers should address municipal sources. Municipalities have responsibilities associated with several important classes of illicit connections, including sanitary collection systems (ownership of collection system), improper connections between sanitary and storm sewer systems, and improper connections from residential or commercial areas. For example, investigations in Houston, Texas, indicated that most of the city's problems associated with nonstormwater discharges to the separate storm sewer system were associated with broken wastewater collection system lines discharging to its stormwater collection system (21).

In general, municipal programs should include legal authority to address the majority of stormwater sources into their municipal system. However, this does not mean that a municipality should have to ensure that every existing residential, commercial, or industrial site within its jurisdiction actively controls its stormwater. Rather, municipalities should develop programs that result in the implementation of practicable controls for high-priority sources that maximize cost-effectiveness by considering possible sources and conditions within the jurisdiction. In addition, EPA must be a partner in efforts to control selected priority sources, such as industrial, federal, and state facilities. For example, some municipalities have indicated that practical problems are associated with controlling stormwater from federal and state facilities. In such cases, a partnership between the municipality and the NPDES authority may be appropriate where the municipality identifies high-risk state and federal facilities for the NPDES authority to consider issuing an NPDES permit directly.

In addition, the Agency should lead national efforts to directly reduce some pollutant sources or find product substitutes. For example, federal requirements under the Clean Air Act have resulted in significant decreases in the use of lead in gasoline, which in turn have resulted in decreases in lead concentrations in urban runoff. Other areas of national regulation and/or pollution prevention efforts that have been suggested are reduction in the amount of zinc in tires, reductions in the amount of copper in brake pads, and lower emission standards for particulate emissions for diesel engines (11).

### *Flexibility in Selecting Measures*

Municipal stormwater management programs should be comprehensive efforts that address a wide range of innovative measures in addition to traditional command-and-control requirements. Federal or state permitting programs generally have limited flexibility to directly implement many types of innovative control strategies in a widespread manner. Requiring municipalities to obtain NPDES permits for their municipal systems could create a regulatory framework that could support municipalities' use of innovative controls, such as market-based incentives.

For example, municipalities can fund stormwater programs with a utility rate system that accounts for the impervious area at a site, which is roughly proportional to the amount of stormwater generated at the site. A survey of 54 stormwater agencies with stormwater utilities located in 19 states indicated that 70 percent of the agencies surveyed based their utility on the amount of impervious area at a site, while an additional 17 percent based their utility on the product of area times an intensity of development, which can approximate impervious area (22). Such a rate system can also consider whether stormwater controls are provided at a site. These approaches create market-based incentives for reducing site imperviousness (thereby reducing stormwater volumes and pollutant loads) and for installing and operating stormwater measures. (See U.S. EPA for a list of 21 municipal stormwater utilities that provide credits for onsite stormwater management [23].)

Municipalities have a wide range of tools for ensuring stormwater control measures occur with new development. For example, municipalities can have zoning provisions that establish setbacks for buffer zones, limit the amount of impervious area, require maintaining minimum amounts of open space, and encourage cluster development. Municipalities can also develop watershed management plans that provide for preservation of floodplains, wetlands, shoreline, and other critical areas. In addition, during the building plan approval process, municipalities can designate, through deed modification or other means, an entity or individual who is responsible for maintaining the stormwater management systems of a new development. Controls on siting, installing, and maintaining septic systems and for ensuring proper sanitary sewer connections can reduce pollutant discharges from municipal separate storm sewer systems.

Other innovative approaches to stormwater management include used oil and/or household hazardous waste municipal collection programs. Municipalities can conduct portions of public outreach programs in a more cost-effective way than other levels of government. For example, municipalities can stencil catchbasins to minimize improper dumping of materials and send informational flyers with water or sewer bills.

Another approach is for a municipality to use pollutant trading concepts to select cost-effective controls. One example of pollutant trading is for a municipality to allow a developer to contribute to an offsite regional stormwater measure where onsite measures are not feasible. Other pollutant trading concepts are discussed in Santa Clara Valley Nonpoint Source Pollution Control Program (11) and U.S. EPA (24). It should be noted that some concerns have been raised regarding trading structural controls for nonstructural controls where opportunities to install structural controls can be lost and the continued implementation of nonstructural controls cannot be assured.

Municipalities can also incorporate voluntary components into their municipal stormwater management programs, such as adopt-a-highway litter programs or adopt-a-stream programs. In addition, the development of stormwater programs at the municipal level can encourage high levels of public input from local groups.

### *Flexibility To Address High-Risk Sources and To Protect Priority Resources and Watersheds*

Controlling pollutants in stormwater involves addressing many and diffuse pollutant sources. The nature of the problem calls for focusing on priority sources and emphasizing controls in priority watersheds. Municipalities are in the best position to evaluate local conditions and to determine local priorities for implementing and overseeing control strategies and measures that ensure the water quality impacts of land use activities in its jurisdiction are mitigated. This is particularly true when evaluating the risks of new development.

Urbanization is a gradual process that spans decades and occurs over a wide region. It is composed of hundreds of individual developments that take place over much shorter time frames. The true scope of water resource degradation associated with urbanization may not fully manifest at the watershed scale for many years. This presents the challenge of evaluating the impact of individual development proposals over the long term at the watershed scale (25) and planning appropriately. Such detailed planning can only occur on the municipal level.[8] Detailed efforts to plan and oversee new development could not (and should not) be undertaken at the federal level.

Municipalities typically have planning processes and administrative systems in place to address some aspects of new development. When municipalities plan for new development, the total development of the area can be considered. This can provide a much more comprehensive basis for planning than when developers plan at the site level. Municipalities can accomplish these tasks with a much greater sensitivity to local conditions and in a more equitable and reasonable manner. In addition, municipalities can develop watershed plans that consider the tradeoffs associated with the placement of onsite controls and regional stormwater management approaches. Some municipalities advocate stormwater control strategies that use a mix of regional controls and onsite controls that reflects watershed hydrology. Advantages of this approach are said to include better control of peak flows; reduced impacts to streams and riparian wetlands; improved pollutant removal efficiencies; lower costs; a significantly higher likelihood of adequate maintenance; and recreational amenity values (26).

The ability of EPA or NPDES states to conduct such detailed planning is limited. For example, EPA indicated that a consideration of possible water quality impacts associated with the timing of releases from onsite stormwater management measures involves a complex array of variables, including the nature and locations of other activities within a watershed, and is generally beyond the scope of the Agency's NPDES general permits for stormwater from construction activities (see 57 FR 41202). Municipal consideration of mitigation measures for numerous smaller projects in a watershed may better maintain the integrity of an aquatic ecosystem.

A goal of the stormwater program should be that municipalities have planning procedures to identify and address the potential impacts of development on water resources. NPDES permits for municipal separate storm sewer systems can assist in reaching this goal by ensuring that municipalities consider the impact of stormwater on surface waters. Traditionally, the major objective of installing separate storm sewers has been to remove as much stormwater runoff from developed lands as soon as possible. To achieve this goal, local governments have constructed thousands of miles of curb, gutter, road side ditches, and other storm sewers to convey stormwaters as quickly and as efficiently as possible to the nearest stream (18). Efforts often focus on channelization projects that attempt to make streams more "efficient" at conveying waters downstream. Extensive channelization projects and other stream "improvements," such as concrete-lined walls or heavy riprap, can destroy the habitat value of streams.

A few communities have developed programs where stormwater is managed for multiple purposes, including controlling water quantity (to avoid flooding and stream scour and to maintain stream flows during dry weather by recharging ground water during storms) and improving water quality. A range of alternative stormwater control measures and facilities can be implemented to serve multiple purposes effectively. The natural cycles and processes that occur before land development are used

[8] EPA has recognized that many local governments typically require sediment and erosion plans, grading plans and/or stormwater management plans that are significantly more detailed and are accompanied by a more rigorous review process than those required under EPA-issued general permits (57 FR 41196).

as a guide for managing stormwater after development has occurred, and natural flow patterns and rates of discharge are retained through special stormwater control facilities and measures. Natural processes are incorporated into the design of many “soft” engineered systems, including vegetated buffers, greenways, revegetation of stormwater systems, wetland creation or retention for stormwater management, and onsite retention, detention, or infiltration systems. Policies emerging from these programs include:

- Reducing peak flows and improving stormwater quality through onsite retention.
- Reducing the volume of stormwater leaving the site using natural infiltration.
- Releasing stormwater from onsite facilities at a rate similar to the predevelopment runoff rate.
- Managing for smaller storm events as well as those larger storm events that can cause major floods.
- Protecting wetlands and floodplains as natural stormwater storage areas.
- Making stormwater facilities amenities of the development (such as retaining natural drainage channels or providing attractive landscaping for stormwater management ponds) and encouraging open space and recreational uses.
- Developing programs that relate erosion and sediment controls during construction with stormwater management after construction is completed.

The implementation of this approach typically involves somewhat higher costs for development plan review by local governments but lower costs for stormwater facility construction, and results in lower social costs.

### *Maintenance of Controls*

The installation of structural controls (e.g., wet ponds, infiltration devices) during the construction phase of new development is often cited as a key component to a successful stormwater program. To continue to operate, these devices need to be maintained every 5 to 15 years. Lack of maintenance is often cited as a leading cause of failure of stormwater management devices.

While NPDES permits for stormwater discharges from construction activities disturbing more than 5 acres can require the installation of stormwater measures during the construction phase of a project, permit coverage for residential and commercial sites ends when the site is stabilized. Therefore, NPDES permits for stormwater discharged from construction sites may not be able to ensure the continued maintenance of these sites. Municipalities are in a better position to require or conduct maintenance activities for these devices. For example, municipalities can require maintenance of stormwater management devices through deed modification prior to site development or through ordinances.

## Moratorium Sources: Which Municipalities?

Public commentors on previous NPDES stormwater rulemakings have identified a number of principles that are critical to successful implementation of NPDES requirements for a stormwater regulatory program (55 FR 48039):

- Municipalities should be regulated as equitably as possible.
- Major sources of pollutants must be addressed through control, treatment, or prevention.
- The approach must be administratively realistic and achievable.
- New development should be addressed.
- Programs must be coordinated or developed on a regional basis to avoid fragmentation or balkanized programs and to support watershed approaches.
- Regional approaches are necessary to address interrelated discharges into the municipal separate storm sewer system.

Municipalities associated with Census-designated UAs or a subset thereof appear to meet most of the criteria in a way that makes them candidates for consideration for Phase II stormwater requirements. Additional municipal candidates for Phase II requirements are pockets of high growth levels outside of Census-designated UAs and areas with large seasonal activities (e.g., some tourist towns) that are not classified as part of a Census-designated UA because of small year-round populations.

### *Equitable Treatment/Major Pollutant Sources*

Currently, NPDES requirements for discharges from municipal separate storm sewer systems focus on core cities, and generally do not address UAs surrounding core cities in a comprehensive manner. The regulations do address 47 counties that were selected because they had significant populations in unincorporated, urbanized portions of the county. In most UAs, however, areas surrounding core cities are broken into incorporated areas and/or minor civil divisions with populations of less than 100,000. These areas are not addressed by current NPDES requirements even though they may be in a heavily populated county. For example, 400 counties have a population of greater than 100,000 but are not addressed by the current NPDES regulations.

At least three factors are important to consider when determining whether municipalities are being regulated as equitable as possible: 1) demographic patterns associated with per capita income; 2) the pollutant sources that are being addressed; and 3) the ability to control major pollutant sources. Some states have also advocated national NPDES requirements to ensure national consistency and to prevent economic disincentives that make it difficult for states and municipalities to implement progressive stormwater management programs (57 FR 41205).

The per capita income of suburban fringe areas is typically significantly higher than the per capita income of core cities. A 1991 report by the National League of Cities indicates that the per capita incomes of residents in the largest cities is only on average 59 percent of the per capita incomes in the surrounding suburbs. The magnitude of these income disparities was cited as a clear indicator of the disparities in tax bases. The report also suggested that continued demographic shifts are expected to increase these differences (27). In addition, municipal governments associated with core cities often provide a greater range of services than surrounding areas, resulting in higher per capita municipal government costs.

As discussed above, the pollutant sources associated with urban stormwater are diffuse in nature and are associated with widespread areas of development. Census data from 1990 indicate that approximately 46 percent of the total area and 35 percent of the total population of UAs containing a city with a population of 100,000 or more are located outside of the core city in suburban fringe areas.[9] As a rough approximation, suburban fringe areas are generating as much stormwater pollution as core cities with a population of 100,000 or more. Failure to address suburban fringe areas outside of these cities would severely limit the ability of the core city to protect receiving waters.

The equity issue is also related to the types of controls that are available to municipalities. Older, densely developed core cities have limited opportunities to control pollutants in their stormwater (8). Areas with substantial new growth, however, including many suburban fringe areas, have greater opportunities to ensure appropriate stormwater management and mitigate impacts to receiving waters associated with new growth.

Between 1970 and 1980, the population of incorporated cities with a population of 100,000 or more (those with municipal separate storm sewer systems addressed by NPDES regulations before October 1, 1992) increased by only 0.6 million, with much of this increase associated with the addition of the populations of 17 cities that had populations of 100,000 or more for the first time. The land area of most of these cities remained the same, while the populations of many large cities decreased.

Most growth in UAs occurs in areas that were not required to obtain an NPDES permit for their stormwater discharge before October 1, 1992. Between 1970 and 1980, the population of UAs outside of cities with a population of 100,000 or more increased 30 times more (an increase of 18.9 million) than the population of these cities. This growth resulted from both increases in population densities of existing urban lands and by the urbanization of previously rural lands. Factors such as lower costs of land, commercial space, and residential housing continue to cause urban sprawl even in UAs that are not experiencing population growth.

Equity and pollutant source considerations would appear at least to require that NPDES requirements be extended to cover suburban fringe municipalities in Census-designated UAs in which one or more large or medium municipal separate storm sewer systems are already subject to NPDES requirements. Municipalities with a large or medium municipal system should not be held solely responsible for implementing NPDES stormwater requirements when stormwater from suburban municipalities limits the opportunities of the core cities to effectively protect water resources.

Perhaps a more equitable approach would be to expand NPDES requirements to cover municipalities associated with Census-designated UAs of a specified size (e.g., 100,000 or 50,000). This approach would ensure that urban centers of similar size and the largest sources of urban runoff would be subject to program requirements.

### *Administratively Achievable/New Development*

In core cities, urban streams are typically already heavily degraded, with limited opportunities for full restoration. Significant opportunities exist in suburban fringe areas, however, to conduct new development in a way that mitigates impacts on water resources. A basic principle of stormwater controls is that developing controls for new development is much more cost effective (8) and institutionally feasible than retrofitting old development. EPA has also indicated that, where properly planned, stormwater controls can *increase* the property values and satisfy consumer aesthetic needs (56 FR 40989).

Municipalities often oversee the development process. They usually have some form of approval or permit program in place. Developers have incentives to comply, because enforcement can be stringent (e.g., stop-work orders), and the developer usually wants to have a workable relationship with the municipality to ensure that future projects proceed smoothly. In addition, the costs of the controls are not borne by the municipality directly but rather by the developer. Several states with

[9] In the United States, most people served by combined sewers are located in cities with a population of 100,000 or more (57 FR 41349). Thus, the percentage of urbanized population served by *separate* storm sewers in suburban fringe areas is higher than indicated above.

progressive stormwater management programs have initially focused on new development (e.g., Maryland, Florida, and Delaware). This is unlike the approach taken in the 1987 amendments to the CWA, which initially focused on core cities with little or no growth and temporarily excluded suburban municipalities. The November 16, 1990, EPA regulations addressed 47 counties and 173 cities. The counties that were addressed where in a handful of states, primarily Maryland, Virginia, Florida, and California. While the Agency was able to address suburban growth in these states, in most parts of the country the regulations only address core cities and exclude suburban development.

Perhaps the biggest challenge associated with Phase II NPDES stormwater requirements for municipalities is the potentially large number of small municipalities that should be addressed. Census-designated UAs offer advantages over broader classifications of metropolitan areas, such as Standard Metropolitan Statistical Areas (SMSAs),[10] in that UAs do not include significant amounts of rural areas or small urban municipalities that are isolated from larger urban centers. In many parts of the country, however, suburban urban fringe areas are broken into a significant number of small municipal entities (see Table 3). In developing Phase II requirements for municipalities, EPA could consider promoting regional approaches, developing tiered requirements for different sizes of municipalities, and limiting requirements or providing exemptions for very small municipalities. For example, the Agency could consider focusing requirements for small municipalities on a few key program components, such as new development, municipal activities that affect stormwater quality (e.g., road building and maintenance), illicit connections, and public education.

### *Regional Approaches*

As discussed above, regional approaches to stormwater management offer a number of advantages, including providing municipalities with the opportunity to pool resources and to address stormwater management with a more holistic watershed approach. Successful programs must face the challenge that municipalities do not follow watershed boundaries. Currently, the NPDES municipal stormwater program principally focuses on core cities with a population of 100,000 or more.[11] If suburban municipalities fail to develop adequate stormwater programs, the ability of core cities adequately to protect the receiving waters of the core city will be limited. As Tucker (18) states,

> Dealing with drainage across jurisdictional lines is important. . . . The ability to look at urban stormwater management from a regional or metropolitan wide perspective is important. The larger drainageways typically flow from one jurisdiction to another and what happens in one entity can impact others. Planning should be approached on a basinwide basis and not stop at jurisdictional boundaries. . . . Once the Phase II regulations for NPDES permits for municipal separate storm sewers become a reality, more metropolitan areas will seriously consider regional approaches to stormwater management.

## Conclusion

Urban stormwater discharges have been shown to be a major source of water quality impairment. Section 402(p)(6) of the CWA requires EPA to identify additional stormwater sources to be regulated to protect water quality. In UAs, pollutants associated with stormwater come from many sources distributed throughout the area of urban development. Commercial and residential areas appear to be significant sources of pollutants, along with certain municipal activities. Municipal governments in UAs must play a significant role in developing and implementing programs that effectively address priority pollutant sources within their jurisdictions. Municipal governments have the critical institutional framework for making the day-to-day decisions to address these problems, to minimize or prevent the risk associated with stormwater from areas undergoing urbanization, and to collect the majority of funds necessary to implement the comprehensive programs needed to address urban stormwater management. The condition of a waterbody is a reflection of watershed management and land use characteristics. To ensure that the waterbody is protected and maintained, citizens must be empowered to work together to that end.

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[10]Unlike Census-designated urbanized areas, SMSAs, which are identified by the Office of Management and Budget, are based on county boundaries and can contain significant rural areas. Urbanized areas are defined to describe population densities. An urbanized area consists of the contiguous builtup territory around each larger city and thus corresponds generally to the core of the SMSA. SMSAs are defined to describe a large population nucleus and adjacent communities that have a high degree of economic and social integration with that nucleus. This designation has been developed for use by federal agencies in the production, analysis, and publication of data on metropolitan areas (28).

[11]The NPDES storm water program also currently addresses unincorporated portions of 47 counties. However, most large counties, including those in many heavily urbanized areas of the country, are currently not subject to NPDES stormwater requirements. Those counties currently addressed by the NPDES storm water program have large populations in unincorporated areas and only represent a few states, notably, California, Florida, Maryland, and Virginia.

**Table 3. Municipalities Associated With Census-Designated UAs Based on 1990 Census Data[a]**

| Class of UA | No. of UAs | No. of Incorporated Places[b] | No. of MCDs[c] | No. of Counties[d] | Total Population (millions) |
|---|---|---|---|---|---|
| All UAs | 396 | 3,624 | 1,655 | 703 | 158.3 |
| 250,000 or more | 103 | 2,672 | 1,022 | 358 | 127.5 |
| 100,000-250,000 | 121 | 490 | 349 | 185 | 18.9 |
| 50,000-100,000 | 172 | 462 | 284 | 258 | 11.9 |
| Phase I municipalities | Parts of 137 | 621 | 0 | 70 | 76.2 |
| UA with large or medium MS4 | 137 | 2,147 | 665 | 280 | 116.8 |

[a] Examples of Census-designated UAs and associated 1990 populations:

| | | | |
|---|---|---|---|
| Brunswick, GA | 50,066 | Ogden, UT | 259,147 |
| Ithaca, NY | 50,132[e] | Albuquerque, NM | 497,120 |
| San Luis Obispo, CA | 50,305 | Albany-Schenectady-Troy | 509,106 |
| Lafayette-West Lafayette, IN | 100,103 | Akron, OH | 527,863 |
| Sioux Falls, SD | 100,843 | Oklahoma City, OK | 784,425 |
| Jacksonville, NC | 101,297 | Salt Lake City, UT | 789,447 |
| Pensacola, FL | 253,558 | New Orleans, LA | 1,040,226 |
| Sacramento, CA | 1,097,005 | Shreveport, LA | 256,489 |
| San Antonio, TX | 1,129,154 | | |

[b] Incorporated places include incorporated cities, towns, villages, and boroughs.

[c] Minor civil divisions (MCDs) include unincorporated towns and townships in 20 states.

[d] County equivalents include counties, parishes in Louisiana, and boroughs in Alaska. Some double counting of counties occurred as portions of several UAs may be in one county. (For example, portions of the Washington UA, Baltimore UA, and Annapolis UA are in Ann Arundel County, Maryland.)

[e] The Ithaca, New York, population does not include student population at Cornell University.


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# *Municipal Permitting: An Agency Perspective*

**William D. Tate**
**Office of Wastewater Enforcement and Compliance, Office of Water,**
**U.S. Environmental Protection Agency, Washington, DC**

This paper presents the U.S. Environmental Protection Agency's (EPA's) perspective regarding the municipal side of the National Pollutant Discharge Elimination System (NPDES) stormwater program. It begins by briefly providing some background information on the stormwater program. It then highlights an EPA review of costs that municipal separate storm sewer systems (MS4s) have incurred or anticipate incurring during the next 5 years. After discussing the types of programs that MS4s proposed in their Part 2 applications, the paper concludes by presenting the current status of the permitting process.

## Background

The Water Quality Act (WQA) of 1987 added Section 402(p) to the Clean Water Act (CWA). In Section 402(p), MS4s serving a population of 100,000 or more must obtain an NPDES permit for their stormwater discharges. Section 402(p)(3)(A) specifically provides that permits for these discharges:

- May be issued on a system- or jurisdictionwide basis.
- Shall include a requirement to effectively prohibit non-stormwater discharges into storm sewers.
- Shall require controls to reduce the discharge of pollutants to the maximum extent practicable; controls may include management practices, techniques, system design and engineering methods, and such other provisions as the Administrator or the state determines appropriate for control of such pollutants.

NPDES permits historically have imposed end-of-pipe controls on industrial and publicly owned treatment works discharges. The legislative history of the WQA, however, indicates that Congress does not consider end-of-pipe controls to be necessarily appropriate for stormwater discharges from MS4s. Consequently, in the November 16, 1990, *Federal Register*, EPA published a final rule intended to reflect the unique nature of discharges from MS4s. The final rule establishes permit application requirements and application deadlines for all MS4s covered under Phase I of the stormwater program. For MS4s required to obtain a stormwater permit, EPA established a two-part permit application process. The Part 1 application primarily focuses on a municipality's existing stormwater management activities and includes the following components:

- General information
- Discharge characterization
- Existing legal authority
- Existing stormwater management programs
- Source identification
- Existing fiscal resources

The Part 2 application requires additional information that builds on the information submitted with the Part 1 application. Rather than emphasizing current stormwater management activities, however, the Part 2 application focuses on what future stormwater management activities an MS4 will adopt. Major components of the Part 2 application are similar to those identified above; however, their level of detail is much greater.

Some of the major highlights of the stormwater program involve:

- Obtaining the adequate legal authority to implement an MS4's stormwater management program.
- Developing estimates of annual pollutant loadings and a schedule to submit seasonal pollutant loadings estimates.
- Developing a monitoring program to run throughout the permit term.
- Developing a site-specific and comprehensive stormwater management program.
- Conducting an assessment of the effectiveness of stormwater controls.

- Conducting a fiscal analysis of the costs to implement the applicant's proposed stormwater management program.

The cornerstone of the stormwater program is the requirement that MS4s must develop site-specific and comprehensive stormwater management programs. MS4s should employ all program requirements identified in the final rule. Given their geographical, climatological, and physical differences, however, MS4s can exercise discretion when establishing priorities for their site-specific stormwater management programs. For example, an MS4 in a densely populated urban corridor is not reasonably expected to have the same program priorities as an MS4 servicing an area experiencing rapid development. Later, the paper presents a few different approaches and types of programs that various MS4s are proposing. First, however, is a brief discussion of the present status of the MS4 permitting process.

## Present Status of the MS4 Permitting Process

### *Effects of the 1990 Decennial Census*

In the November 16, 1990, *Federal Register*, EPA identified 219 municipalities required to seek coverage under an NPDES stormwater permit. Appendices F and H of 40 CFR 122 identified 73 of these municipalities as large MS4s. Similarly, Appendices G and I of 40 CFR 122 identified 146 municipalities as medium MS4s. EPA based these 219 identifications on the definition of a municipal separate storm sewer system, which incorporates population data from the latest Decennial Census. In this case, the 1980 Census helped identify the 219 MS4s. Recently, however, the results of the 1990 Decennial Census have become available and, consequently, affect more municipalities. EPA is currently drafting a *Federal Register* notice (FRN) that identifies 42 additional municipalities (30 cities and 12 counties) that now meet the definition of a medium MS4 based on the results of the 1990 Census. Sixty percent of the new cities now required to seek NPDES permits are in the state of California, while 33 percent of the new counties are located in the state of Florida.

In contrast to the number of newly identified MS4s, the 1990 Census found that five cities and two counties dropped in population to below 100,000. Although these municipalities no longer satisfy the definition of a medium MS4, two counties and one city still participate in the stormwater program.

Next, the paper discusses municipalities that the appendices of 40 CFR 122 did not originally identify but that nevertheless have been designated as Phase I sources.

### *Designated MS4s*

Section 402(p)(2)(E) and 40 CFR 122.21(b)(4)(iii) and (7)(iii) provide that permitting agencies may use their authority in designating municipalities that operate separate storm sewer systems and serve populations of less than 100,000 as regulated MS4s. EPA has compiled some preliminary information on the number of these municipalities, some of which are volunteering to participate in the program. Based on the best information available to date, it appears that states and EPA regions designated small municipalities as regulated MS4s primarily because they share common watersheds or are interconnected with a nearby regulated MS4. In at least two states, EPA observed that all incorporated cities below a population of 100,000 were designated if they are within the boundary of a regulated MS4 (county); therefore, these municipalities must submit a stormwater permit application. EPA is currently trying to determine what permit application deadlines have been established for these designated MS4s and whether they are participating as coapplicants with a regulated MS4 or are filing as single applicants.

Table 1 summarizes some preliminary data on the number of cities, counties, and special districts that have either been designated or who are voluntarily participating in the program as Phase I stormwater sources.

EPA considers the figures presented in Table 1 preliminary because additional information is still pending from three Regional Water Quality Control Boards (RWQCBs). Some general observations, however, are noteworthy. First, 65 percent of the designated cities in Region 4 are located in the state of Florida. In the case of the 47 designated special districts, 26 are state departments of transportation, 11 are flood control districts,

**Table 1. Summary of MS4 Designations by EPA Region**

| EPA Region | Designated Cities | Designated Counties | Special Districts |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 |
| 3 | 13 | 5 | 2 |
| 4 | 236 | 9 | 6 |
| 5 | 1 | 0 | 8 |
| 6 | 0 | 0 | 6 |
| 7 | 1 | 0 | 2 |
| 8 | 1 | 0 | 2 |
| 9[a] | 127 | 7 | 14 |
| 10 | 1 | 1 | 7 |
| Total | 380 | 22 | 47 |

[a]Additional information pending three RWQCBs in the state of California.

four are state universities, three are port authorities, and three represent a group of water control districts.

### *Effects of Combined Sewer Overflow Exclusions*

The NPDES stormwater regulations allow municipalities to deduct the population served by combined sewer systems from the total population served by the MS4. To date, this provision has exempted 29 municipalities as Phase I sources. An additional eight large MS4s have been reclassified as medium MS4s. Table 2 provides a breakdown of combined sewer overflow (CSO) exclusions by EPA region.

### *Current Permit Applications*

As noted earlier, the NPDES stormwater regulations require MS4s to submit a two-part permit application. Table 3 provides the latest information available on the number of submissions of Part 1 and Part 2 applications. *This table specifically excludes permit application submissions for the states of California and Nevada.*

The next section of this paper summarizes the results of a recent EPA effort to document costs that MS4s have incurred or are expected to incur over a 5-year period. The information represents the most specific information EPA has received to date on stormwater costs associated with the stormwater program.

## Review of MS4 Program Cost Data

EPA recently conducted an analysis of Part 2 applications in an effort to gain a better understanding of costs associated with implementing the municipal effort of the stormwater program. EPA is currently completing a review that documents the costs that 20 MS4s expect to incur or have incurred as a result of implementing their stormwater management programs. These costs are based on fiscal information provided in Part 2 permit applications. The primary purpose of this effort is to assist EPA's Office of Water in determining the cost burden that results from developing and implementing programs in response to the NPDES stormwater regulations. To that end, EPA has developed a preliminary draft estimate for the total annual per capita cost to develop and implement the stormwater management program over a 5-year period. Some background information on the analysis may provide a basis for better understanding the results.

**Table 2. Summary of CSO Exclusions by EPA Region**

| EPA Region | Medium MS4s | Medium to Large MS4s | Large MS4s | Total |
|---|---|---|---|---|
| 1 | 5 | 1 | 0 | 6 |
| 2 | 7 | 4 | 2 | 13 |
| 3 | 2 | 0 | 1 | 3 |
| 4 | 0 | 0 | 0 | 0 |
| 5 | 6 | 0 | 2 | 8 |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 0 | 2 | 2 | 4 |
| 8 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 1 | 1 |
| 10 | 1 | 1 | 0 | 2 |
| Total | 21 | 8 | 8 | 37 |

**Table 3. Summary of Part 1 and Part 2 Submissions by EPA Region**

| EPA Region | Medium MS4s, Part 1 | Medium MS4s, Part 2 | Large MS4s, Part 1 | Large MS4s, Part 2 |
|---|---|---|---|---|
| 1 | 3 | 0 | 0 | 0 |
| 2 | 0 | 0 | 5 | 5 |
| 3 | 10 | 0 | 11 | 10 |
| 4 | 24 | 0 | 20 | 15 |
| 5 | 12 | 0 | 5 | 5 |
| 6 | 7 | 0 | 9 | 7 |
| 7 | 7 | 0 | 3 | 1 |
| 8 | 3 | 2 | 3 | 1 |
| 9[a] | 2 | 0 | 4 | 3 |
| 10 | 6 | 0 | 4 | 2 |
| Total | 74 | 4 | 64 | 49 |

[a] California RWQCBs have issued permits for 130 applicants. Information is still pending from three RWQCBs. The state of Nevada has issued final permits for its regulated MS4s. Permit application submission figures for EPA Region 9 reflect those applications that are currently under review.

### *Applications Reviewed*

EPA selected the Part 2 applications for this analysis from among those that had been submitted to permitting agencies by the November 16, 1992, deadline. EPA selected municipalities located throughout the country to obtain a more realistic representation of the cost data. Thus, eight MS4s are located in the eastern part of the United States, seven in the central part, and five in the west. Selected municipalities also fall within eight of the nine Rainfall Zones of the United States. The 20 municipalities reviewed are:

- Aurora, Colorado
- Baltimore, Maryland
- Charlotte, North Carolina
- Dallas, Texas
- Denver, Colorado

- Fairfax County, Virginia
- Harris County, Texas
- Honolulu, Hawaii
- Houston, Texas
- King County, Washington
- Lakewood, Colorado
- Norfolk, Virginia
- Philadelphia, Pennsylvania
- Phoenix, Arizona
- Prince Georges County, Maryland
- Seattle, Washington
- Tampa, Florida
- Tucson, Arizona
- Tulsa, Oklahoma
- Virginia Beach, Virginia

Based on the 1990 Decennial Census, the combined populations of these MS4s totaled over 11.3 million. Fifteen percent of these MS4s have populations exceeding 1 million, 75 percent have populations between 250,000 and 1 million, and 10 percent have populations of less than 250,000. With the exception of Aurora and Lakewood, Colorado, all of these MS4s were previously identified as large MS4s in the November 16, 1991, *Federal Register*.

### Grouping of Cost Data

This analysis broke down the actual and estimated costs that MS4s reported in their applications into the following eight major program components:

- Public education
- Monitoring
- Commercial and residential
- Construction
- Industrial facilities
- Maintenance of controls
- Improper discharges
- Miscellaneous

EPA selected these categories because they generally reflect the variety of costs reported in the applications and are largely consistent with the categories outlined in the permit application regulations. Each of these eight major categories were further subdivided into specific program components. An underlying objective of this effort was to determine the additional financial burden the stormwater program imposed on municipalities. Whenever possible, therefore, a breakout between new and existing program costs was made for each reviewed application.

### Limitations

At this point, it is crucial to note some of the limitations associated with this analysis. First and foremost are limitations with the sample. Applications selected represented mostly large MS4s; therefore, EPA cannot be certain that these results are fully representative of costs that medium MS4s would report. Nearly 68 percent of the regulated MS4s were not required to have submitted their Part 2 applications at the time EPA conducted this analysis. Consequently, this limits the availability of Part 2 applications that the analysis could have included. One other important consideration with regard to the sample selection is that the results may be overstated in instances where MS4s are subject to more stringent local and regional controls or other environmental initiatives for stormwater management.

The second limitation is that, in many instances, MS4s did not include the cost of projects normally included in a capital improvement program (CIP). Although these projects often pertain to flood control, future CIP projects typically will have features that also address stormwater quality. Therefore, although providing the additional benefit of improved stormwater quality may be in response to the stormwater program, the analysis results do not typically reflect these associated costs. In contrast, EPA did not attempt to exclude significant costs that MS4s reported for programs unreasonably attributed to the stormwater program, even though they probably would have existed regardless of the stormwater program.

The third limitation reflects the difficulty in making direct comparisons between applicants. The regulations provide flexibility to the MS4s with regard to proposing stormwater management programs that reduce or eliminate the contribution of pollutants in stormwater discharges to the maximum extent practicable. The diverse approaches to stormwater management that MS4s have proposed reflect this flexibility. MS4s also used a variety of methods to report annual cost data.

Inconsistencies that existed within individual applications account for the fourth limitation. In many instances, the text describing a proposed stormwater management program component often did not correlate with the cost information provided. For example, the application may have indicated that an existing program would cover an activity, but the fiscal analysis section of the application did not provide the costs associated with the existing program. Often, MS4s reported that an existing stormwater management program was “absorbing” a new proposed program. The MS4s, however, provided no separate fiscal data in the application.

Finally, the results of this analysis suggest that in a number of instances MS4s both overreported and underreported costs. EPA did not attempt to exclude any reported costs from this analysis. Consequently, EPA is attempting only to document average costs.

### *Results*

Of the 20 MS4 applications reviewed, the average annual reported cost for both new and existing programs ranged from $211,000 or $0.76 per capita (Tampa Bay, Florida) to $98 million or $190.85 per capita (Seattle, Washington). Table 4 highlights the ranges of average annual costs that municipalities reported.

Using population data from the 1990 Census, EPA calculated a preliminary average annual per capita cost for both new and existing programs of $23.91. Based on information reported by MS4s, it appears that costs for new programs or initiatives typically ranged from 10 to 15 percent of the average annual cost. As noted earlier, EPA reviewed Part 2 applications mostly from large MS4s. As medium MS4 applications become available, EPA anticipates examining cost data from some of these applications as well.

## Programs the Part 2 Applications Proposed

Having reviewed some of the cost data, this paper will now present more specific details and examples of the types of stormwater management programs proposed in a number of Part 2 permit applications. The discussions's structure follows the organization of the Part 2 application (e.g., adequate legal authority, source identification, characterization data, and management programs). The discussion's scope is confined to some observations on a sample of eight Part 2 applications.

### *Legal Authority*

According to the stormwater regulations, municipalities must demonstrate that they possess the adequate legal authority to implement their stormwater management activities when they submit their Part 2 applications. In the Part 2 guidance manual, EPA acknowledges that this is not always possible if an MS4 lacks the enabling legislative authority to develop the necessary ordinances. In these cases, applicants need to provide a schedule as to when adequate legal authority will be obtained.

**Table 4. Ranges of Average Annual Costs Reported by Municipalities**

| Average Annual Costs | Number of Municipalities |
|---|---|
| Less than $1,000,000 | 4 |
| $1,000,000 to $5,000,000 | 6 |
| $5,000,000 to $10,000,000 | 5 |
| Greater than $10,000,000 | 5 |

Six municipalities stated that they had obtained the adequate legal authority to carry out the requirements of the stormwater regulations. One municipality anticipated having necessary legal authority by the spring of 1993, and one anticipated having the authority within 2 years. As a general note, municipalities reported existing ordinances that addressed most of the legal authority requirements of the regulations, especially with regard to controlling improper discharges, illegal dumping, and erosion and sediment control provisions. The comprehensive nature of the stormwater regulations, however, required most municipalities to establish new ordinances or update existing ones, particularly for obtaining the necessary authority to conduct monitoring and surveillance of stormwater discharges from private sources.

Several municipalities provided detailed excerpts or, in some cases, the complete text of their comprehensive stormwater ordinances. For example, Seattle, Washington, and Prince Georges County, Maryland, provided the text of their grading, erosion, and control ordinances, while King County, Washington, provided the text of both its water quality ordinance and its pesticide regulation. Ordinances of both Seattle, Washington, and Prince Georges County, Maryland, addressed the requirements of the stormwater regulations in addition to other local or regional initiatives, such as the Puget Sound Water Quality Management Plan and the Chesapeake Bay Preservation Act, respectively.

### *Source Identification*

The principle requirement of the source identification component of the Part 2 application is to identify any previously unknown major outfalls and to compile an industrial inventory. The industrial inventory must then be organized on a watershed basis. Perhaps one of the biggest challenges of the permit application is identifying all major outfalls that comprise the storm sewer system. Several MS4s reported using the analytical capabilities of their geographic information systems (GISs) to identify potential locations of outfalls not previously identified in the Part 1 application. A few applicants specifically noted that this was a particularly effective approach. Although a GIS is not a requirement of the stormwater regulations, EPA recognizes that GISs are well suited for many of the activities associated with stormwater management. Out of the eight applications reviewed, at least six reported having GIS capability, while one applicant anticipated having GIS capability in the near future.

### *Characterization Data*

The characterization data portion of the Part 2 application requires an MS4 to submit the results of wet weather sampling with the application. More specifically, applicants must submit sampling data for five to 10 outfalls from at least three representative storm events. EPA has not had an opportunity to conduct a detailed analysis of this information. Some general observations, however, follow.

First, although many of the applicants reported completing their wet weather sampling requirements, they typically expressed similar difficulties in doing so. MS4s often noted that they had to sample several more than the requisite minimum of three storm events to obtain the number of requisite samples. In one instance, an applicant reported that it took a total of 18 storm events to obtain the requisite number of samples. Applicants also frequently cited that they had to discard samples because a particular storm's duration and rainfall accumulation did not meet the requirements of a representative storm event. Other problems commonly cited included sampling during storm events with frequent starts/stops and the logistics of mobilizing sampling crews at the onset of a storm event. The unpredictability of storm events and the logistics associated with wet weather sampling prompted at least four of the eight MS4s to use automatic samplers.

In at least one instance, an MS4 obtained approval to use available historical data to satisfy the majority of their sampling requirements. In this case, the applicant needed to sample one additional storm event at two sampling sites. Applicants often cited that concentration data compared well with the results of the NURP study. In general, the eight MS4s reported that the results of the analysis of composite samples exhibited characteristic concentrations for metals such as copper, cadmium, zinc, and lead. The sampling data also suggest that the concentration of organic contaminants often fell below detection levels for composite samples. Individual grab samples, however, detected many organic contaminants.

The second major component of this portion of the application requires the municipalities to estimate annual pollutant loadings. EPA allows MS4s the flexibility of selecting an appropriate method to estimate pollutant loadings. A majority of the eight applicants elected to use computer models such as SWMM, P8, and the CDM Nonpoint Source model to estimate annual loadings. A few applicants elected to use the simple method developed by the Metropolitan Washington Council of Governments.

EPA expected that computing pollutant loadings would satisfy at least two objectives. First, loading estimates would raise the level of awareness within municipalities of the relative magnitude of pollutant loadings associated with stormwater discharges. Second, the estimates could be used as part of a screening process when establishing priorities for stormwater management activities. One applicant specifically noted using loading estimates in this manner. Some applicants noted that these estimates had limited value and that other means of representing sampling data would be more appropriate.

The Part 2 application requires applicants to maintain an ongoing monitoring program for the duration of the term of the permit. An approach proposed by the city of Baltimore, Maryland, warrants special mention. Baltimore proposed a comprehensive and phased approach to monitoring which consists of four major components:

- Dry weather stormwater outfall monitoring
- Pollutant source tracking
- Long-term trend monitoring
- Stormwater runoff monitoring

The city identified the following six major goals to its monitoring program:

- *Dry weather screening:* This entails developing a "water quality dry weather flow" database to assist in isolating watersheds that may require further investigation as potential sites of illicit connections.
- *Dry weather source tracking:* This entails conducting investigations to detect and eliminate sources of dry weather flows.
- *Toxicity testing:* A pilot toxicity testing program would evaluate the impact of pollutants on a receiving water ecosystem due to unknown contaminants and synergistic effects.
- *Stream ecosystem database:* A database that describes the biological integrity of the receiving streams could assist in analyzing long-term trends, prioritizing management practices, and assessing the effectiveness of management programs.
- *Stormwater runoff and best management practice (BMP) assessments:* This effort could characterize stormwater runoff quality and assess the effectiveness of BMPs that may be used in the future.
- *Receiving stream water quality database:* This entails establishing dry and wet weather flow water quality databases for major stream systems that can be used for conducting long-term assessments and determining the effectiveness of watershed management programs.

The city's proposal to establish a stream ecosystem database is particularly noteworthy because it would provide the city with a baseline of its existing biological community (e.g., benthic macroinvertebrate population and diversity). It would also provide a basis from which to conduct a long-term assessment of the effectiveness of watershed management activities. More importantly, it would allow the opportunity to gain a greater understanding of the effects of stormwater discharges on a specific aquatic habitat. Finally, the city is closely coordinating its monitoring program with several subwatershed studies to determine the effectiveness of certain BMPs in protecting receiving water quality, including aquatic habitat.

### *Management Programs*

Of course, the cornerstone of the two-part permit application is the requirement that MS4s develop site-specific and comprehensive stormwater management programs. Each applicant must address four major areas in its application:

- A description of structural and source control measures to reduce pollutants in runoff from residential and commercial areas.
- A description of procedures to detect and remove illicit connections and a program to control improper disposal.
- A description of structural and source control measures to reduce pollutants in runoff from industrial areas.
- A description of programs to maintain structural and nonstructural BMPs to reduce pollutants from construction sites.

In most instances, applicants elect to follow the application format established in the November 16, 1990, *Federal Register* to describe their management programs. From an initial review of eight applications, it appears that many MS4s are proposing approaches that entail phasing in components of their programs over the permit term. Applicants not only cited economic reasons for this approach but also the desire to ensure that a particular BMP is effective before it is implemented on a systemwide basis. For example, several applicants reported initiating studies to determine what factors significantly influence the performance of a specific structural control before its use on a systemwide basis. Pending the results of these studies, applicants proposed modifying their watershed management programs accordingly. While a phased approach may be reasonable in some instances, there are cases where the permitting authority may not consider it appropriate.

In one of the reviewed cases, an applicant proposed a phased approached to its illicit connections program. Although EPA acknowledges the effort necessary to detect and isolate the source of an illicit connection, a phased approach appears to overlook the immediate benefits of a fully implemented illicit connections program. This is especially true for municipalities in densely populated urban corridors that have both separate and combined sewer systems.

Implementing a comprehensive stormwater management program is a complex effort that requires the participation of numerous inter- and intragovernmental agencies. Before implementing a program, a municipality needs to establish program priorities. It may be helpful at this point to briefly illustrate one applicant's approach to establishing criteria for prioritizing basins for watershed management activities.

In 1987, King County, Washington, completed a "Basin Reconnaissance Program" that provided the information necessary to establish an initial basin planning prioritization scheme. The county provided a complete set of the results of this effort with its Part 1 application. King County established four major prioritization categories with commensurate criteria for each category. The major categories and criteria are as follows:

- Existing problems
  - Landslides
  - Erosion/Sediment
  - Flooding
- Future problems
  - Unincorporated land in King County
  - Subdivision/Plat activities
  - Population growth
  - Permitted residential units
- Existing resources
  - Stream habitat
  - In-stream resources
  - Wetland value
  - Wetland storage potential
  - Water quality potential
- Urgency/Timeliness
  - Other Agency interest
  - Opportunity to integrate with other programs

For all 37 basins identified, King County assigns a numerical rating to each criterion and a composite score for each major category, then establishes a total basin numerical rating. After completing basin prioritization ranking, the county proceeds with a six-step basin planning process. The first step is the formation of a basin plan team consisting of a project manager, biologists, geologists, water quality specialists, engineers, resource planners, mapping and GIS technicians, and graphics support. In the next step, the team collects data that include information on rainfall, flow levels, geological makeup, geomorphology, habitat complexity and diversity, fish utilization, and water quality. The basin plan team may spend up to 2 years compiling data.

The third and fourth steps entail computer modeling of a basin's hydrology and predicting the effects of alternative land-use activities. The results of the modeling efforts assist in developing a current and future conditions report that documents existing conditions and provides an analysis of future trends.

The fifth step entails drafting a basin plan and conducting public meetings and hearings. After necessary modification, the team finalizes the draft plan and submits it to the King County Council for approval. Following approval, the King County Surface Water Management (SWM) Division is responsible for implementing the basin plan. King County SWM anticipated completing 12 of its 37 basin plans by the end of 1992.

The King County basin planning program reflects a resource-intensive effort and a commitment to reducing the deleterious effects of stormwater discharges. Municipalities that are essentially new to stormwater management may find elements of King County's program not only innovative and informative but also adaptable to their needs.

MS4s proposed some general observations about particular program components. First, a majority of the applications placed a heavy emphasis on minimizing future problems associated with stormwater management, specifically in the area of long-term planning for future development. In several instances, MS4s reported that they had either completed or initiated the development of stormwater management master plans for major watersheds.

Also, MS4s are increasingly requiring approval of erosion and sediment control plans before approving a site plan or allowing construction to begin. Similarly, many MS4s require permanent BMPs (privately financed), such as installation of retention/detention basins for all new developments over a certain size area. MS4s also frequently reported that inspections programs had been or are being established to ensure maintenance of publicly and privately owned BMPs over their useful life. In at least one instance, an MS4 provides an economic incentive to install BMPs by establishing a BMP crediting system for non-single-family residences.

A couple of applicants also reported a substantial commitment to preserving open space. In one case, a municipality reported that it is pursuing a "Greenways" program that could potentially preserve 16,000 acres as open space. To date, 400 acres have been preserved. Similarly, one county has established a stream valley park system. All major streams in the county are to become part of the park system. In this instance, the county has imposed an additional requirement: new development must provide for buffer zones or easements.

Over the long term, approaches like these may minimize the need to construct costly structural controls to remove pollutants from stormwater discharges. Moreover, this preventative approach to stormwater management can potentially reduce the significant costs that some municipalities are incurring to restore degraded stream corridors and wetlands. EPA recognizes that this is a contentious issue. It is encouraging to note, however, the emphasis municipal applicants are placing on community involvement and public outreach programs. The "adopt-a-stream" program and other similar community-based environmental programs, such as household hazardous waste collection, routinely appeared in Part 2 applications.

Paraphrasing one applicant's comment, the goals of a stormwater management program cannot be fully achieved unless there is participation and consensus among those who are affected. Otherwise, past practices will continue to have a detrimental influence on valuable water resources within our communities.

## Current EPA Activities in the Area of MS4 Permitting

Several EPA regions and state permitting authorities have supported the formation of an MS4 steering committee to look at specific issues pertinent to MS4 permits. The steering committee is looking at program components and permits that may be suitable as model programs or model permits. It also will assist in determining how to incorporate core elements of a stormwater program into an MS4 permit. Lastly, the steering committee will be exploring alternative mechanisms of exchanging information on stormwater management. The committee will coordinate this particular effort with ongoing outreach activities at EPA.

EPA also is conducting a municipal assessment project (MAP) that continues to examine the progress of the municipal permitting process. This entails compiling information on the status of both permit applications and permit development. Whenever possible, EPA will suggest future improvements or enhancements to the MS4 permitting process. EPA is continuing to compile information on MS4s designated by state permitting agencies and EPA regions. Other objectives of the MAP include examining the Part 2 applications in more detail to identify programs as potential model candidates.

As the permitting process moves from the development of permit applications to permit development, EPA anticipates distributing information on the progress of permit development to permitting authorities. Hopefully, this approach will benefit all those participating in the permitting process.

# *Municipal Stormwater Permitting: A California Perspective*

**Thomas E. Mumley**
**California Regional Water Quality Control Board, San Francisco Bay Region, Oakland, California**

## Abstract

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), began a program for control of stormwater discharges from urban areas in 1987. The initial focus of the program has been on the municipalities in Santa Clara and Alameda counties. An areawide approach was promoted in which all the cities in each county, the county, and the county flood control agency worked collectively. The Santa Clara and Alameda programs were issued municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits in June 1990 and August 1991, respectively. These efforts have focused on implementation of stormwater management programs rather than on the NPDES permit itself. Essentially, the permit serves as an enforceable mechanism requiring implementation of the programs developed by the municipalities and approved by the Regional Board.

The municipal stormwater management programs all involve similar elements, including public information/participation, elimination of illegal discharges, public agency activities, control of industrial/commercial stormwater discharges, new development management, stormwater treatment, program evaluation, and monitoring. The process of developing these programs has uncovered several issues and problems, mostly nontechnical, which could potentially impede successful implementation. On the other hand, workable solutions to most of these problems have also been identified. The essential ingredient of the process that has enabled progress has been a cooperative, proactive relationship between the Regional Board and municipalities. Continuation of this process is expected to result in a realistic and meaningful municipal stormwater NPDES permit program.

## Background

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), is the state water pollution control agency responsible for protection of San Francisco Bay and its tributaries. San Francisco Bay is a highly urbanized estuary and as such receives significant loads of pollutants through discharges of urban runoff. The responsibilities of the Regional Board include water quality control planning, control of nonpoint sources of pollution, and issuance and enforcement of NPDES permits. Using its authorities, the Regional Board began a program for control of stormwater discharges from urban areas in 1987. The initial focus of the program was on the most highly urbanized areas, which include the municipalities in Santa Clara and Alameda counties. An areawide approach was promoted in which all the cities in each county, the county, and the county flood control agency worked collectively.

Santa Clara and Alameda counties developed their programs through a strategic planning process (1). The process followed a series of steps that involved establishing program goals and framework; compiling existing information; assessing water quality problems through collection and analysis of data and modeling of pollutant loads; identifying, screening, and selecting appropriate control measures; and establishing a plan for implementation. This planning process lead to development of a comprehensive stormwater management plan by each program (2, 3). In addition, institutional arrangements, legal authorities, and fiscal resources for implementation were addressed.

The efforts of the Regional Board and the Santa Clara and Alameda municipalities were well under way when the stormwater National Pollutant Discharge Elimination System (NPDES) permit regulations were promulgated in November 1990. The Regional Board found the information that the planning process followed by the two areawide programs provided was equivalent to federal permit application requirements. Consequently, the Regional Board issued municipal stormwater NPDES permits to the Santa Clara and Alameda programs in June 1990 and August 1991, respectively, which required implementation of their stormwater management plans. Issuance of these "early" permits served to recognize the accomplishments of the two programs and to provide a focus on implementation actions while avoiding the time delays and costs associated with the promulgated application requirements. We also have focused attention on the adequacy and effectiveness of the stormwater management plans rather than the permits. Essentially, the permit serves as an enforceable mechanism requiring implementation of the programs developed by the municipalities and approved by the Regional Board.

The efforts of the Santa Clara and Alameda municipalities have provided a meaningful framework for and the essential elements of an effective stormwater management program. A similar approach is being followed by municipalities in the other urban areas of the San Francisco Bay region. The process of developing these programs has uncovered several issues and problems, mostly nontechnical, which could potentially impede successful implementation. On the other hand, workable solutions to most of these problems have also been identified. The following discussion provides a status report of the San Francisco Bay programs, a description of the elements of the stormwater management programs, and insight into the problems encountered and their solutions.

## San Francisco Bay Region Municipal Stormwater Programs

In the San Francisco Bay region, nearly all municipalities in urban areas have stormwater management programs and NPDES permits under way or under development. The Regional Board has encouraged, recognized, or required areawide programs in which all municipalities within a watershed or municipal systems that interconnect are managed under one program. In addition, municipal flood management agencies are included as co-permittees. The California Transportation Department (Caltrans) is required to implement a stormwater management program for all storm drain systems within the region. The municipal stormwater programs in the San Francisco Bay region are listed below.

- Santa Clara Valley Nonpoint Source Pollution Control Program, including the county and all cities:
  - Population approximately 1,500,000
  - NPDES permit issued June 1990
- Alameda County Urban Runoff Clean Water Program including the county and all cities:
  - Population approximately 1,250,000
  - NPDES permit issued October 1991
- Contra Costa Cities, County, District Stormwater Pollution Control Program including the county and all cities:
  - Population approximately 800,000
  - Part 1 Application submitted May 1992
  - Part 2 Application due May 1993
- San Mateo County Urban Runoff Clean Water Program, including the county and all cities:
  - Population approximately 650,000 (no city nor the county has population more than 100,000)
  - Combined Parts 1 and 2 Application due May 1993
- Caltrans, including all operation, maintenance, and construction activities:
  - Incomplete application submitted July 1992
  - Complete application due May 1993
- City of Vallejo:
  - Population more than 100,000 (as of 1990 Census)
  - Part 1 Application due March 1993
  - Part 2 Application due March 1994
- Cities of Fairfield and Suisun City Joint Program:
  - Population more than 100,000
  - Part 1 Application due March 1993
  - Part 2 Application due March 1994

## Municipal Stormwater Program Elements

The municipal stormwater management programs all involve similar elements except for Caltrans, which will not be discussed here. These include public information/participation, elimination of illegal discharges, public agency activities, control of industrial/commercial stormwater discharges, new development management, stormwater treatment, program evaluation, and monitoring. The activities associated with each of these essential program components are presented below.

### *Public Information/Participation*

This element is considered the most important early action and is the cornerstone of effective pollution prevention. Its objectives are to inform the public, commercial entities, and industries about the proper use and disposal of materials and waste and to correct practices of stormwater runoff pollution control. Activities include development of general and focused information materials and public service announcements. Participation activities include citizen monitoring programs, stenciling of storm drain inlets with no dumping signs, and organized creek cleanups.

### *Elimination of Illegal Discharges*

Elimination of illicit connections to the storm drain system and the prevention of illegal dumping are other essential early action elements. The objective is to ensure that only stormwater or otherwise authorized discharges enter storm drains. Activities include inspection of storm drain outfalls, surveillance of storm drain systems, and enforcement actions.

### *Public Agency Activities*

Many public agency activities affect stormwater pollution. Some activities prevent or remove stormwater pollution, while other activities are sources of pollution. The objective of this element is to ensure that routine municipal operations and maintenance activities are initiated or improved to reduce the likelihood that pollutants are discharged to the storm drain system. Activities include street sweeping; maintenance of storm drain inlets, lines and channels, and catch basins; corporation yard management; and recycling programs. Coordination of road maintenance and flood control activities with the stormwater management program is also included.

### *Control of Industrial/Commercial Stormwater Discharges*

Industrial and commercial sources may contribute a substantial pollutant loading to a municipal storm drain system. The objective of this element is to identify and effectively control industrial and commercial sources of concern. Activities include compiling a list of industrial and commercial sources, identifying appropriate pollution prevention and control measures, and inspecting facilities. The focus is not only on facilities associated with industrial activity as defined in the stormwater regulations but on any facility that conducts industrial activities, as well as commercial facilities such as automotive operations and restaurants. This effort is expected to complement federal and state industrial stormwater permitting efforts.

### *New Development Management*

Areas of new development and redevelopment offer the greatest potential for implementation of the most effective pollution prevention and control measures. The objective of this element is to reduce the likelihood of pollutants entering the storm drain system from areas of new development and significant redevelopment, both during and after construction. Activities include review of existing local permitting procedures and modification of the procedures to identify and assign appropriate site design, erosion control, and permanent stormwater control measures.

### *Stormwater Treatment*

The initial focus of the stormwater management programs is on pollution prevention and source control. Treatment of stormwater is expected to be a costly alternative. There may be opportunities, however, for installation or retrofitting of structural controls. The objectives of this element are to study the various treatment alternatives available, to test the feasibility of conducting the activities, and to determine the effectiveness of the treatment through pilot-scale projects. Initial focus has been on existing wetland systems, flood control detention basins, and treatment of parking lot runoff.

### *Program Evaluation*

Stormwater management programs are expected to change as they mature. Consequently, they should have built-in flexibility to allow for changes in priorities, needs, or levels of awareness. The objective of this element is to provide a comprehensive annual evaluation and report of program effectiveness. Measures of effectiveness include quantitative monitoring to assess the effectiveness of specific control measures and detailed accounting of program accomplishments and funds and staff hours expended. The annual report provides an overall evaluation of the program and sets forth plans and schedules for the upcoming year. The annual report is considered a program’s self audit and provides a mechanism to propose modifications to the stormwater management plan in response to program accomplishments or failures. The annual report also serves as the key regulatory tool for providing accountability and public review in accordance with the NPDES permit.

### *Monitoring*

Monitoring is an essential component of any pollution control program. The objectives are to obtain quantitative information to measure program progress and effectiveness, to identify sources of pollutants, and to document reduction in pollutant loads. The success of a monitoring program can be measured by the ability to make more informed decisions on a program’s direction and effectiveness. Monitoring activities include baseline monitoring of storm drain discharges and receiving waters and focused special studies to identify sources of pollutants and to evaluate the effectiveness of specific control measures. Types of monitoring include water column measurements, sediment measurements, and nonsampling and analysis measurements, such as number of outfalls inspected or amount of material removed by maintenance. Toxicity identification evaluations are an integral component of monitoring programs in the San Francisco Bay area.

## Municipal Stormwater Program Problems

The process of developing these programs has uncovered several issues and problems, mostly nontechnical in nature, that could potentially impede successful implementation. The first step towards avoiding or solving these problems is understanding what they are and how they may affect a program. The following discussion provides insight into the more common problems.

### *Internal Agency Coordination*

Municipalities are public agencies, often with multiple departments serving different functions, that are an integral part of stormwater management. The missions and actions of separate departments are often carried out without coordination with other departments. Commitments or actions by planning department personnel that are not coordinated with public works result in problems. All affected departments must participate in development of a stormwater management program. The stormwater program plan also must clearly identify the roles and levels of participation of all involved departments.

### *External Agency Coordination*

In addition to coordination within a municipality, communication and coordination is necessary between adjacent cities, the county, and regional organizations such as flood control and wastewater treatment agencies. Historically, there may have been little need for coordination, or problems encountered by other programs may have created barriers. As with the internal agency issue noted above, all affected agencies must participate in the program development process and clearly understand their implementation responsibilities.

### *Resistance by Key Individuals*

Individuals play a strong role in local government. Consequently, one or more key individuals can make or break a program. Often one individual causes the internal and external coordination problems noted above. Also, in the early development stages of a program, until dedicated personnel are identified, individuals may resist the additional work load required of them to make the program work.

### *Financial Resources*

Without dedicated financial resources, a stormwater management program is destined to fail. Programs that do not start the process to secure dedicated funds early in program development find themselves unable to commit to a meaningful program. The process of establishing a stormwater utility, assessment district, or other funding mechanisms is cumbersome and requires strategic planning.

### *Legal Issues*

Initial review of existing local ordinances may result in the conclusion that sufficient legal authorities already exist. Later on in the development process, however, when specific implementation activities are identified, the existing authority may be found to be too vague or unsuitable. Review of legal issues should be part of the annual evaluation process.

### *Competing Mandates*

Mandates by other programs within a municipality or by external agencies may directly conflict with stormwater program mandates. Examples include fire departments prohibiting inside or covered storage of certain materials or the obvious conflict between eradication of vegetation with herbicides in flood control channels and water quality concerns.

### *Problem Awareness/Understanding*

To solve or manage a problem, one must first understand the problem. Effective pollution prevention requires a new way of thinking that may be foreign to those accustomed to more conventional engineering solutions. A subset of this issue involves those who deny that a problem exists.

### *Resistance to Maintenance Responsibility*

Municipal programs are expected to result in installation of some structural controls, particularly in areas of new development or significant redevelopment. A frequently encountered barrier is that municipalities are not willing to take on the additional maintenance responsibility associated with new structural controls.

### *Problem Sources Beyond Municipal Authority*

Many sources of stormwater pollution involve atmospheric emissions, automobile wear (e.g., brakes, tires), and household products over which a municipality has no control. Transportation related issues are beyond the control of a single municipality. State and federal coordination with local programs is essential.

### *Lack of Tools To Evaluate Effectiveness*

The effectiveness of pollution prevention measures is difficult to quantify. Natural variability in stormwater quality may mask improvements associated with certain control measures. Surrogate measures and analytical tools to evaluate stormwater management program effectiveness should be better defined.

## Municipal Stormwater Program Solutions

The efforts of the Regional Board and the municipalities in the San Francisco Bay area have overcome many of the problems noted above. The essential ingredient of the process that has enabled progress has been a cooperative, proactive relationship between the Regional Board and municipalities. A discussion of some of the solutions that have evolved follows.

### *Carrot and Stick Approach*

At the onset of each new municipal program, the Regional Board has made it clear that stormwater pollution is a serious problem that must be dealt with and that the best solutions will only happen at the local level. The carrot has been an offer to the municipalities to control their own destinies rather than waiting for the powers that be in Sacramento or Washington to determine what they can or cannot do. This approach allows the municipalities to identify and select the measures that are workable for them and, most importantly, that are most cost-effective. On the other hand, the Regional Board has also made it clear that participation is not voluntary and that failure to commit to meaningful actions will result in enforcement actions.

### *Round Table Forum*

Contrary to the conventional regulatory approach, in which the regulator demands and the regulatee reacts, the Regional Board has promoted a round table forum in which all involved parties work collectively and cooperatively to identify solutions that address the concerns and means of all involved. This approach has also provided a mechanism for participation by all affected internal and external public agencies.

### *Regular Meetings*

The Regional Board has met in the round table format with municipalities throughout the program development process. Meetings have been held at least monthly. This has allowed for timely and effective decision-making. Focused work groups to address specific problems or program elements have also been formed.

### *Minimization of Bureaucracy*

The stormwater pollution problem is not a conventional problem that can be solved by conventional means. Any program is doomed to fail if it is mired in red tape. To promote innovative solutions, the regulators must be willing to promote innovative regulatory mechanisms.

### *Flexibility*

To truly present a carrot to entice municipalities and promote innovative solutions, the regulator must be willing to be flexible. No one solution exists for stormwater pollution problems. What works in one municipality may not work in another. Also, flexibility provides a reward mechanism for those municipalities who are committed and proactive.

### *Phased Approach*

The phased approach promotes a strategy based on goal setting, identification of actions, planning and preparation for planned actions, small-scale implementation, and finally full-scale implementation. Evaluation is essential to each step. It must be recognized that some actions may be implemented immediately or in the short term, while others may take many years to fully implement.

### *Pilot Studies*

Although many control measures have been demonstrated to be effective, such measures often need testing within the conditions of a specific municipality. Pilot studies also provide an opportunity to identify factors such as operation and maintenance parameters or non-technical factors such as legal issues that may not be apparent. They also provide a mechanism for demonstrating acceptability to concerned parties and should be considered a first step leading to successful wide-scale implementation.

### *Annual Program Audit*

Recurring evaluation is essential. At a minimum, program participants and the regulator should annually evaluate program progress. This comprehensive annual audit should identify program successes as well as failures and should provide a mechanism to steer the program in the most effective direction.

## Conclusions

Focusing on the described municipal stormwater program elements and taking a cooperative approach to solving problems have led to the development of successful stormwater management programs by municipalities in the San Francisco Bay area. Although program implementation is in the early stages and total success cannot be claimed, the programs are successful in that they present a workable framework for implementation of meaningful actions. Essential to the process is strategic planning, accountability, and recurring evaluation of program direction, success, and failure.

The NPDES permit issued to a municipality is not going to solve the stormwater pollution problem—it can only serve as a tool to facilitate action. The success of the municipal stormwater permit program will be recognized when municipalities are committed to action, and NPDES permits merely require municipalities to do what they have committed to do.

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# Stormwater Management Ordinance Approaches in Northeastern Illinois

**Dennis W. Dreher**
**Northeastern Illinois Planning Commission, Chicago, Illinois**

## Abstract

Stormwater drainage and detention is widely regulated by local ordinances in northeastern Illinois. Early ordinances, going back to about 1970, focused exclusively on the prevention of increased flooding and nuisance drainage problems. Recent ordinances address the objectives of preventing flooding and channel erosion, preserving predevelopment hydrology, protecting water quality and aquatic habitat, providing recreational opportunities, and enhancing aesthetic conditions.

The basis for many of the newer ordinances is a model ordinance developed by the Northeastern Illinois Planning Commission. The "Model Stormwater Drainage and Detention Ordinance" calls for "natural" drainage practices to minimize increases in runoff volumes and rates and for detention basins that control the full range of flood events and effectively remove stormwater pollutants.

The model ordinance requires detention designs that limit the 100-year release to 0.15 $ft^3$/sec/acre and the 2-year release to 0.04 $ft^3$/sec/acre. These rates are actually lower than the local predevelopment runoff rates and are based on observed capacities of the downstream channel system. Detention design also must incorporate water quality mitigation features, including permanent pools or created wetlands, stilling basins, and the ability to avoid short-circuiting. Further, the model ordinance strongly discourages detention in onstream locations or in existing wetlands.

As multipurpose ordinances are implemented, several issues remain. Some municipal officials are concerned about the aesthetics and maintenance needs of wetland-type detention basins and natural drainage practices, such as vegetated swales. Technical debate continues over the effectiveness of on-line and onstream detention, both from a water quality and flood prevention perspective. Also, the appropriateness of using existing wetlands for stormwater detention remains to be determined.

## History

Stormwater drainage and detention has been widely regulated by local ordinances in northeastern Illinois since the early 1970s. Early ordinances were implemented because of a recognition that rapid suburban development was causing more frequent and more damaging flooding and drainage problems. Flooding and drainage problems in the region are exacerbated by the very flat landscape; typical ground slopes range from 0.5 to 4 percent. As a result, even a slight increase in flood volumes and rates can expose large additional areas to flooding.

Most early ordinances required storage of the 100-year rainfall event. These ordinances were based on requirements developed by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). MWRDGC requires sewer permits for new development within Cook County, the largest and most populous in the six-county northeastern Illinois region. Many communities in the outer "collar" counties followed MWRDGC's lead and developed similar ordinances.

At the same time that municipalities began to implement stormwater detention controls for new development, most also required via subdivision ordinances that new development be drained by curb and gutter and storm sewer systems. This drainage philosophy was intended to reduce local drainage problems but resulted in increased rates and volumes of runoff.

The quality of urban runoff began to receive some attention in the late 1970s with the completion of the Areawide Water Quality Management Plan by the Northeastern Illinois Planning Commission (NIPC) (1). This plan reported much higher pollutant loads for urban land-use categories compared with rural land uses. As a consequence, the plan recommended that stormwater loadings of suspended solids and biological oxygen demand (BOD) be reduced by 50 percent by appropriate best management practices (BMPs) for all new development. Despite the recommendations of the plan, few changes occurred in the stormwater management strategy of local governments, which addressed exclusively the *quantity* of runoff but not the *quality.*

## Assessment of Ordinance Effectiveness

In 1986 and 1987, large areas of northeastern Illinois were besieged by major floods, with total damage estimates exceeding $100 million. In some locales, flood flows exceeded the reported 100-year frequency event. Of particular concern was the observation that large flood damages had occurred in watersheds that had developed extensively since the implementation of detention ordinances in the early 1970s. This lead to the suspicion that detention was not preventing increases in flood flows.

To address these concerns, NIPC was funded by the Illinois Department of Transportation, Division of Water Resources, to investigate the effectiveness of existing stormwater detention ordinances. First, a literature review was performed to assess the effectiveness of detention in various locales around the country. Next, a comprehensive watershed modeling study was performed to evaluate both the effects of urbanization and a range of existing and proposed stormwater detention controls. The study concluded that the detention standards that most communities required were not adequate to prevent increases in flooding due to new development (2). Other local studies initiated by the Soil Conservation Service reached similar conclusions (3). Several specific weaknesses were identified:

- Detention volumes were inadequate to store the intended 100-year design event due to outdated rainfall statistics and/or simplistic hydrologic design techniques.
- Required 100-year release rates were typically based on site predevelopment runoff rates rather than observed instream flood flow rates.
- Because detention outlets were designed to explicitly control only the 100-year event, smaller flood events (e.g., the 2-year event) typically passed through detention facilities with inadequate control.

The study also noted two problems in addition to flooding impacts. The first was increased stream channel erosion, caused in part by the increased magnitude and frequency of small floods. The second was water quality impairment due to inadequately controlled urban runoff.

## New Model Ordinance Approach

With the preceding problems in mind, NIPC was contracted to develop an updated model stormwater ordinance. This "Model Stormwater Drainage and Detention Ordinance" (4) was developed with the assistance of a regionwide, multiagency technical advisory committee. The primary purposes of the ordinance are to minimize the stormwater-related effects of development on downstream and local flooding, stream channel erosion, water quality, and aquatic habitat.

The model ordinance is intended to apply to all development, including redevelopment. It requires the submittal of a basic drainage plan consisting of a topographic map, a detailed description of the existing and proposed drainage system, and a description of sensitive environmental features such as wetlands. An advanced drainage plan is required for sites larger than 10 acres. The advanced plan should include flow rates, velocities, and elevations at representative points in the drainage system for events up to the 100-year. The following are some important ordinance standards and criteria:

- *Runoff reduction hierarchy:* The ordinance requires the evaluation of site design practices that minimize the increase in runoff volumes and rates. A preference is stated for, in order, minimization of hydraulically connected impervious surfaces, use of open vegetated swales and channels and natural depressions, and infiltration practices. Traditional storm sewer approaches are discouraged unless other measures are not practical.
- *100-year release rate:* The peak 100-year discharge should not exceed 0.15 $ft^3$/sec/acre. This release rate is related to the capacity of the downstream channel/floodplain system for extreme flood events. The referenced detention effectiveness evaluation indicated that this release rate should prevent development-related increases in flooding for watersheds up to at least 30 square miles in size (and probably much larger).
- *2-year release rate:* The peak discharge for events up to the 2-year event should not exceed 0.04 $ft^3$/sec/acre. This release rate is designed to minimize increases in the magnitude and frequency of the instream 2-year event, which is sometimes associated with bankfull flow conditions. This requirement is intended to minimize increases in stream channel erosion. This release rate also will provide extended ponding for small storm events, which will enhance pollutant removal.
- *Detention storage requirements:* The design maximum storage should be based on the runoff from the 100-year, 24-hour event. Storage should be computed based on hydrograph methods, such as TR-55 or TR-20. Design rainfall should be based on the Illinois State Water Survey's Bulletin 70 (5), which supersedes the U.S. Weather Bureau's Technical Paper No. 40 (6). Bulletin 70, which is based on a precipitation database that is more extensive and more current, reports a 100-year, 24-hour rainfall of 7.6 in., while Technical Paper 40 recommends 5.8 in.

- *Water quality design features for detention:* The ordinance indicates a preference for wet detention basins over dry extended detention facilities to maximize pollutant removal potential. For wet basins, the ordinance includes design criteria for depths, shoreline slopes, permanent pool volume, and inlet/outlet orientation. For dry extended detention basins, the ordinance includes design criteria for velocity dissipation at inlets and inlet/outlet orientation.

- *Detention in floodways and stream channels:* The ordinance discourages detention in designated floodways, particularly in onstream locations with upstream drainage areas larger than about 1 to 2 square miles. The principal concerns with onstream detention are that it may be less effective in mitigating stormwater pollutants and it allows stormwater pollutants to be discharged into stream channels without adequate pretreatment.

- *Detention in wetlands:* Use of existing wetlands to accommodate stormwater detention requirements is strongly discouraged. The ordinance requires that all stormwater be stored and routed through a 2-year water quality detention facility (consistent with the previous design criteria) before being discharged to a wetland. The ordinance allows *additional* storage, up to the 100-year event, to be provided in a wetland if it can be shown that the wetland is low in quality and that proposed detention modifications will maintain or improve its habitat and other beneficial functions.

Overall, the new model ordinance is one of the most stringent in the country in its storage and release rate requirements for minimizing the effects of development on downstream flooding. The new ordinance also includes, for the first time, some basic requirements for BMPs to mitigate stormwater quality effects.

## Recent Improvements in Local Stormwater Regulations

As an advisory agency, NIPC has no authority to require compliance with its model ordinances. Similarly, there is no comprehensive state requirement for local stormwater regulations. Because of recent experience with devastating floods, however, many communities were eager to consider alternatives to stormwater standards that were a decade or more old.

The process of evaluating new ordinances was facilitated by state legislation, passed after the floods of 1986 and 1987, that authorized northeastern Illinois counties to establish stormwater management committees (SMCs). These committees, with equal representation from county government and municipalities, were authorized to develop comprehensive, binding stormwater management plans. These plans included both watershed-based flood remediation measures as well as uniform, countywide stormwater regulations.

So far, comprehensive countywide ordinances have been implemented in two counties, DuPage (7) and Lake (8). These ordinances address traditional stormwater drainage and detention concerns as well as floodplain management, soil erosion and sediment control, and stream and wetland protection. The ordinances incorporate many standards from the NIPC models and address multipurpose objectives of preventing flooding and channel erosion, preserving predevelopment hydrology, protecting water quality and aquatic habitat, providing recreational opportunities, and enhancing aesthetic conditions. Probably the most remarkable element of these new ordinances is their inclusion of some basic stormwater BMPs that are intended to address both stormwater quantity and quality concerns.

Countywide stormwater planning efforts also have begun in Cook, Kane, and McHenry Counties. Many communities in these counties have individually begun to update their ordinances. Some of the impetus for ordinance updates has come from watershed-based groups, such as the Butterfield Creek Steering Committee. This group developed a comprehensive ordinance for seven watershed communities all faced with similar problems of overbank flooding, stream channel erosion, and water quality degradation (9).

Other communities are updating ordinances based on requirements of the Illinois Environmental Protection Agency (IEPA) as a condition for facility planning area amendments for expanded wastewater service. These requirements are based on provisions of the Illinois Water Quality Management Plan and essentially require that development within new FPA expansions not adversely affect water quality, either due to point or nonpoint sources.

The IEPA also is delegated to implement the new NPDES requirements for stormwater discharges. In particular, as part of its new general permit for construction site activities, IEPA requires the development of a pollution prevention plan that must include provisions for soil erosion and sediment control as well as stormwater BMPs such as detention facilities, vegetated swales and natural depressions, infiltration practices, and velocity dissipation measures (10). While the construction site general permit does not mandate the adoption of ordinances, it does provide further incentive to local governments to begin to add stormwater quality control measures to their existing ordinances.

Regionwide enthusiasm for inclusion of water quality BMPs in stormwater ordinances is still somewhat limited because of a lack of awareness among many stormwater engineers, local officials, and the public of the adverse effects of stormwater runoff on water quality and aquatic life. This perception appears to be at least partly related to the long-term degradation of urban water bodies in the region and the lack of a prominent focal point, such as a Chesapeake Bay or Puget Sound, for viewing stormwater quality impacts.

## Some Current Issues

As multipurpose stormwater ordinances are adopted throughout the region, several issues remain. Some municipal officials are concerned about the aesthetics and maintenance needs of wetland-type detention basins and natural drainage practices, such as vegetated swales. Technical debate continues over the effectiveness of on-line and onstream detention, both from a water quality and flood prevention perspective. Also, the appropriateness of using existing wetlands for stormwater detention remains to be resolved.

Perhaps the most important consideration of local government officials regarding stormwater drainage is public acceptance, which generally translates as the avoidance of “nuisance” drainage conditions. Some commonly cited nuisance concerns include extended saturation or ponding on lawns or swales, “weedy” vegetation, mosquito breeding potential, and wet detention areas. These concerns have driven many communities to require highly engineered drainage systems, including curbs and gutters, storm sewers, and concrete channels, which rapidly convey runoff from the site. Some public works officials also argue that engineered drainage systems are less expensive to maintain.

There is growing support, however, in other parts of the country and in a few northeastern Illinois communities for “natural” drainage practices using vegetated swales, channels, and filter strips and created wetlands. In addition to providing significant pollutant removal and runoff reduction benefits, natural practices may be much less expensive to install and, at least to some, are preferred aesthetically over engineered systems. Progress in gaining acceptance of natural drainage systems has been slow in northeastern Illinois. Successful ongoing demonstration projects, innovative new corporate campus developments, and improved public education should be helpful in advancing natural drainage approaches.

Onstream stormwater detention is a desirable alternative to many site design engineers in the region. In a typical situation, such facilities generally do not provide regional detention for the entire upstream watershed; rather, they serve the storage requirements of a development adjacent to the floodplain. As previously mentioned, however, there are significant concerns about the effects and effectiveness of onstream facilities. These facilities alter the free-flowing nature of streams, creating impoundments susceptible to sedimentation and eutrophication. Impoundments can impede the upstream migration of fish and the downstream drift of benthic organisms. Onstream detention essentially uses the stream as a treatment device. Because of typically shorter residence times relative to offline facilities, however, onstream facilities may not be very effective in trapping stormwater runoff pollutants and protecting downstream water bodies. While the appropriateness of onstream detention in northeastern Illinois merits additional debate, currently this debate is not fully considering the potential adverse water quality and habitat impacts of onstream facilities.

Another unresolved issue is the appropriateness of using existing wetlands for stormwater detention. Section 404 permits have been issued for the incorporation of detention into existing wetlands and mitigation wetlands. If a wetland is impounded without the introduction of fill material, a Section 404 permit may not even be required. Limited water quality protection is provided by several new stormwater ordinances and the NIPC model ordinance, which require pretreatment of stormwater before it is discharged into a wetland. Even if stormwater quality effects are reasonably mitigated, however, detention in a wetland can radically affect its hydrology. In particular, detention is likely to pond water more frequently and at greater depths than in a natural wetland. Such alterations can adversely affect sensitive plant communities and wildlife.

## Conclusions

Stormwater management ordinances have evolved dramatically in northeastern Illinois since their introduction over 20 years ago. Always a leader in flood prevention, northeastern Illinois now has some of the most stringent standards in the nation for detention volumes and release rates.

Evolving from an early emphasis on local drainage and flood prevention, many ordinances now recognize the importance of water quality mitigation and habitat protection. Some newer ordinances reflect a revised philosophy of stormwater management that takes advantage of natural drainage and storage functions, with the objective of limiting stormwater runoff rates, volume, and quality to predevelopment conditions. Much remains to be learned, however, about effective designs for BMPs such as wetland detention, filter strips, and infiltration practices.

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# *The Lower Colorado River Authority Nonpoint Source Pollution Control Ordinance*

**Thomas F. Curran**
**Lower Colorado River Authority, Austin, Texas**

## Abstract

Urban development can be managed to control nonpoint source pollution using a variety of methods. The method selected is typically a function of the jurisdictional agency's authority (or lack thereof), the use and desired quality of the receiving waters, and the impact on and acceptance by the public.

The Lower Colorado River Authority (LCRA) is a conservation and reclamation district created by Texas legislation. LCRA is responsible for the conservation, control, and preservation of the waters of the Colorado River and its tributaries within a 10-county area. Given this responsibility but not land-use control authority, LCRA has developed a nonpoint source pollution control ordinance with a technology-based approach.

The ordinance requires a large percentage of the pollutants generated from new development to be removed before stormwater discharge from the property. A technical manual accompanies the ordinance and explains how to calculate the expected increase in pollution and the various management practices a developer may employ to achieve the required pollutant removal standards. The developer and engineer determine what combination of management practices are most compatible with their site and development plan.

This paper provides the methodology and primary features of the ordinance and technical manual. The reasoning behind this approach is explained, with discussion regarding the strengths and weaknesses of a technology-based ordinance.

## Introduction

The Lower Colorado River Authority (LCRA) is a conservation and reclamation district created by the Texas legislature in 1934. LCRA is also a self-sufficient public utility company. The authority's responsibilities are many and include energy generation, water supply, flood control, management of certain public lands, and preservation and conservation of the waters of the lower Colorado River.

While given these responsibilities, LCRA has limited authority and can only exercise powers expressly given by the legislature. As such, LCRA cannot regulate land use, impose zoning or site development restrictions, or assess taxes. LCRA can, however, promulgate ordinances to control water pollution within its 10-county statutory area.

With these powers and limitations, LCRA has developed an ordinance to control nonpoint source (NPS) pollution from urban development. The ordinance does not impose any land-use regulations other than to establish a technology-based pollutant reduction standard for new development.

## Background

In 1988, the LCRA board of directors approved a water quality leadership policy stating LCRA's goals regarding water quality protection. This policy directed staff to develop a program to control NPS pollution within the 10-county area, commencing with the area of the Highland Lakes.

The Highland Lakes are a chain of seven lakes located west of Austin, Texas. The lakes were created in the 1930s and 1940s for flood control, water supply, and hydroelectric generation. In the early 1980s, the area around the lakes experienced tremendous growth in development activity. This growth prompted concern about the long-term health of the lakes.

## A Pollution Control Approach

From the outset, LCRA was limited in the number of options available to manage development for control of NPS pollution. We realized, however, that it must be attacked in several ways. The initial effort was a public education program, the highlight of which was a 30-minute video entitled, “Pointless Pollution: America’s Water Crisis,” narrated by Walter Cronkite.

Realizing that public education alone would not protect water quality, LCRA staff began addressing the control of NPS pollution through a regulatory program. Lacking land-use control or zoning power, LCRA selected a strategy to reduce the quantity of pollution generated by new development that would otherwise be received by the lakes.

In December 1989, the LCRA board of directors adopted the Lake Travis NPS Pollution Control Ordinance, the first of its kind ever promulgated by a river authority in the state of Texas. In March 1991, a similar ordinance was passed to cover the upper Highland Lakes, which includes Lakes Buchanan, Inks, LBJ, and Marble Falls.

## A Nonpoint Source Control Ordinance

The main strategy of the Lake Travis NPS Pollution Control Ordinance is to establish a set of pollution reduction performance standards. Pollution reduction would be through three methods: 1) removal of a specified percentage of the projected increase in annual NPS pollution load; 2) streambank erosion protection via stormwater detention requirements; and 3) employment of erosion controls during construction.

### *Pollution Reduction Standards*

LCRA’s primary goal was to develop a pollution prevention strategy to protect the lakes. At the same time, consideration was given to producing feasible standards that would not prevent development activity.

The basic requirement of the ordinance is the removal of 70 percent or more of the increased pollution generated over background or undeveloped conditions. Higher removal rates are required for steeply sloped property or land located adjacent to the lakes. The required removal rates were chosen first from a water quality standpoint, but also were considered feasible. Analysis of existing developments and the anticipated performance of best management practices (BMPs) showed possibilities of significant land-use restriction if higher removal standards were employed. Additionally, members of LCRA’s board of directors represent their respective counties or service areas, a majority of which are predominantly rural. While the board adopted an environmental leadership policy, its concern about imposing regulations that could adversely affect local economic development was clear.

### *Streambank Erosion Control*

Urbanization of a site or area can have a great impact on the downstream conveyance system. As pavement and rooftops replace the natural soil and vegetative cover, the magnitude and frequency of runoff increases dramatically.

Just as runoff from an undeveloped watershed has carved out a stream channel over time to convey typical runoff events, the increased volume and frequency of runoff from an urbanized area will reconfigure the streambank to create a larger conveyance system. The result is erosion of streambanks transporting sediment to receiving water bodies, degrading of undercut streams, removal of aquatic habitat, and loss of public and private property.

The approach LCRA has taken to control streambank erosion is to require detainment of postdeveloped runoff to predeveloped runoff conditions for the 1-year design storm. Stream morphology is generally dictated by the 2-year storm event.

To simplify the permitting process, the technical manual provides the required detention volume in inches of runoff as a function of impervious cover. These detention volume requirements can be incorporated into the use of BMPs to meet the pollutant removal performance standards.

### *Temporary Erosion Control*

The ordinance requires erosion and sedimentation to be controlled throughout the development process. For permitted activities, an erosion control plan is required for review and approval. Activities not requiring a permit, such as the construction of a single-family home, also require erosion controls to be in place until revegetation occurs.

The technical manual provides guidance for appropriate erosion controls. These strategies include minimization of area cleared; physical controls such as silt fences, brush berms, and rock berms; downstream vegetative buffers; diversion of upstream flow; flow spreading; contour furrowing; loose straw or jute netting for soil protection; and use of structural BMPs as sedimentation basins during construction.

## Technical Manual

The ordinance is accompanied by a technical manual that provides explanation and guidance for the applicant or engineer. Included in the technical manual are permitting procedures, pollutant loading calculations, and design standards and efficiencies of management practices.

### *Types of Pollution*

Urbanization causes numerous forms of pollution. Analysis of all pollutant elements through a permitting program would encumber both the applicant and review body. LCRA has classified these forms of pollution into three distinct groups important to the protection of the lakes: sedimentation, eutrophication, and toxins. LCRA then selected an indicator pollutant to represent these categories. Indicator pollutants are total suspended solids (TSS) for sedimentation, total phosphorus (TP) for eutrophication, and oil and grease (O&G) for toxins.

- TSS consist of colloidal and settleable particulate matter. In alkaline waters such as those of the Highland Lakes, metals tend to precipitate and become particulate matter. In addition, some organic compounds such as chlordane and polychlorinated biphenyls tend to be adsorbed onto sediment particles.
- TP can be indicative of other nutrients. While the nitrogen cycle is different, plant and microbial uptake occurs for both elements.
- O&G, while encompassing both nontoxic and toxic organic compounds, represents petroleum hydrocarbon pollutants, including carcinogens such as benzene and toluene and chlorinated compounds such as pesticides and herbicides.

These indicator pollutants are used to represent the array of pollutants generated. It is reasonable to assume that removal of these indicator pollutants will result in removal of other pollutants not specifically analyzed.

### Pollutant Loads

A mass loading equation is used to calculate the pollutant load under existing and developed conditions. This determines the increase in pollution generated over background conditions. The equation is a product of annual runoff volume and the average stormwater pollutant concentration.

The pollutant load is calculated in pounds per year and is represented as follows:

$$L = A * RF * Rv * C * K,$$

where L = annual pollutant load (pounds)
A = area of development (acres)
RF = average annual rainfall (inches)
Rv = average runoff-to-rainfall ratio
C = average pollutant concentration (mg/L)
K = unit conversion factor (0.2266)

The runoff-to-rainfall ratio equation used is as presented in the Metropolitan Washington Council of Governments document *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* This regression equation simplifies the runoff-to-rainfall relationship to a function of impervious cover as follows:

$$Rv = 0.05 + (0.009 * IC),$$

where IC is impervious cover in percent

Background and developed pollutant concentrations for the indicator pollutants are provided. These values were acquired primarily from screening local and national reports. The average pollutant concentrations used for indicator pollutants under background and developed conditions are shown in Table 1.

**Table 1. Average Pollutant Concentrations for Indicator Pollutants**

| | Background (mg/L) | Developed (mg/L) |
|---|---|---|
| TSS | 48 | 130 |
| TP | 0.08 | 0.26 |
| O&G | 0 | 15 |

The manner in which this information is supplied within the technical manual results in reasonable estimates of a development's potential pollution impact while making calculations simple and consistent.

### Selection of Management Practices

The technical manual provides design criteria and estimated removal efficiencies for BMPs. The manual is intended to provide guidance to the applicant in selecting BMPs. The applicant must select the BMPs that will enable the development to meet the criteria of the ordinance. The basic strategy for selecting BMPs is to match the pollutant removal requirements with site and development characteristics. Consideration must be given to drainage area, soil type, and topography to select BMPs effectively.

The technical manual provides the expected removal efficiencies for BMPs with a performance history. Most of this data is based on criteria presented in nationally published documents. For structural BMPs, a percent removal efficiency is provided for each indicator pollutant. This is then multiplied by the percent of the total average annual runoff volume to be captured by the proposed BMP. The product is the expected removal efficiency of that BMP. This is done for each indicator pollutant. The analysis and performance standard for O&G is applied only to developments other than single-family residential use. The focus on O&G is on commercial land and parking lots instead of single-family residential neighborhoods. Efficiencies used for each BMP are shown in Table 2.

Other BMPs for which removal efficiencies are provided include vegetated filter strips, street sweeping, and pollution source removal credit for using an integrated pest management plan.

The manual promotes the use of innovative practices as long as the applicant can document the potential effectiveness of the practice. LCRA may also require, by ordinance,

**Table 2. Expected Removal Efficiencies of Selected BMPs**

| | Pollutant | | |
|---|---|---|---|
| Best Management Practice | TSS | TP | O&G |
| Sedimentation basin | 60 | 20 | 10 |
| Sand filtration | 70 | 33 | 30 |
| Extended detention | 70 | 60 | 30 |
| Retention basin | 80 | 80 | 80 |
| Infiltration practices | 80 | 80 | 80 |

that innovative BMPs be monitored at a cost borne by the applicant. Some innovative practices include water quality catch basins (oil/grit separators), peat/sand filters, zeolite filters, and wet ponds. While wet ponds have a proven track record in portions of the United States, their performance, and more particularly their maintenance requirements, in semiarid regions warrants further scrutiny.

### *BMPs in Series*

Based on the removal efficiencies of known BMPs and the removal requirements of the ordinance, development with moderate or high impervious cover may need to provide BMPs in series to meet the ordinance performance standards. One of the unknowns at this juncture is how BMPs operate in series. LCRA currently assumes that the total removal is the sum of the individual BMP removal performances. This is an assumption that warrants further analysis from monitoring BMPs in series.

## Example of Ordinance Application

A commercial establishment desires to develop 200,000 $ft^2$ of retail space and is looking at a 23-acre undeveloped site in the Austin, Texas, area. What would be required for the development to meet LCRA's NPS ordinance?

The site plan layout shows parking for 1,200 vehicles. With access drives and loading areas, the impervious cover provided for vehicular traffic is about 400,000 $ft^2$. The proposed total impervious cover is 600,000 $ft^2$, or 60 percent of the site area.

The average annual rainfall in Austin is 32.5 in. Applying the pollutant load calculations shown in the technical manual,

$$L = A * RF * Rv * 0.2266 * C,$$

yields the average pollutant concentrations shown in Table 3.

With a pollutant removal standard for the site of 70 percent:

**Table 3. Pollutant Concentrations for Austin Example Site**

| | Background (mg/L) | Developed (mg/L) |
|---|---|---|
| TSS | 407 | 12,992 |
| TP | 0.68 | 26.0 |
| O&G (calculated for paved area only, at 100% IC) | 0 | 963 |

- TSS removal = (12,992 - 407) ∗ 0.70 = 8,810 lb
- TP removal = (26.0 - 0.68) ∗ 0.70 = 17.7 lb
- O&G removal = (963 - 0) ∗ 0.70 = 674 lb

The applicant proposes a weekly street sweeping program for general maintenance of the area. The pollutant removal efficiencies assumed for this practice with a vacuum-type sweeper are 20 percent for TSS, 10 percent for TP, and 15 percent for O&G.

The site is gently sloping and does have adequate soil for percolation. Infiltration is desirable; however, it must be preceded by a sediment removal practice according to the technical manual.

To meet the streambank erosion control criteria, a site with 60 percent IC must provide detention for 1 in. of runoff. Therefore, structural BMPs should be sized to also meet this criteria.

The designer decides to try a sedimentation basin followed by an infiltration basin. With 60 percent IC, a 1-in. capture volume will collect 89.7 percent of the average annual runoff based on historical rainfall data and runoff/rainfall relationships. The removal efficiencies of these ponds are the product of the BMP efficiency and percent of average annual runoff captured, as shown in Table 4.

**Table 4. Remove Efficiencies of Sedimentation Basin and Infiltration Basin BMPs**

| Sedimentation Basin | Infiltration Basin |
|---|---|
| TSS - 0.60 ∗ 0.897 = 53.7 % | TSS - 0.80 ∗ 0.897 = 71.6 % |
| TP - 0.20 ∗ 0.897 = 17.9 % | TP - 0.80 ∗ 0.897 = 71.6 % |
| O&G - 0.10 ∗ 0.897 = 9.0 % | O&G - 0.80 ∗ 0.897 = 71.6 % |

To test whether the above controls would meet the ordinance's performance standard requirements, the following equation is used:

$$\text{Total BMP Series Eff.} = [1-((1-E_1)*(1-E_2)*(1-E_3))]*100$$

where

$E_1$ = removal efficiency of first BMP
$E_2$ = removal efficiency of second BMP
$E_3$ = removal efficiency of third BMP

TSS Eff. (total) = [1-((1-0.2)*(1-0.537)*(1-0.716))]*100 = 89.5 percent

TP Eff. (total) = [1-((1-0.1)*(1-0.179)*(1-0.716))]*100 = 79.0 percent

O&G Eff. (total) = [1-((1-0.15)*(1-0.09)*(1-0.716))]*100 = 78.0 percent

Therefore, the above controls would meet the performance standard requirements of the ordinance. Had infiltration not been a viable option, other potential solutions include 1) a street sweeping program with a 1-in. volume extended detention basin followed by 8.4 acres of vegetative filter strip (fair condition, 2- to -7 percent slope) or 2) a street sweeping program with three extended detention ponds, each of 2-in. capture volume.

## Administration

### *Maintenance Agreements*

Maintenance of BMPs is critical to their long-term performance. Without maintenance, the effective life of a BMP may be limited to a couple of years. Relying on good faith or volunteer efforts has not shown to be an effective way to maintain these pollution controls.

The ordinance requires that a NPS Best Management Practice Maintenance Permit be issued upon acceptable completion of construction. Whether through a homeowner's association or through the land owner as an individual, a maintenance association must be formed. The maintenance association is to post financial security or create a fund for the purpose of maintaining all BMPs implemented to meet the ordinance.

### *Enforcement*

A necessary portion of any regulatory program is the ability to impose penalties for not complying with the regulations. The ordinance contains a violations section that allows financial penalties to be imposed for violations of a provision of the ordinance.

## Case Application

The ordinance is relatively new, and there have been few opportunities to evaluate its effectiveness. Two projects of note have shown the impact that the ordinance has had on development.

### *LCRA Office Complex*

The first project of note is construction of LCRA's general office buildings. While not located in an area under the purview of the ordinance, LCRA chose to make a leadership statement by applying ordinance standards to the office complex.

The offices are located on 11.7 acres of land and consist of 250,000 $ft^2$ of office space with close to 600 parking spaces. Site IC is approximately 55 percent. Due to site constraints, innovation had to be applied to achieve the performance standards of the ordinance.

A series of BMPs are employed on the site, including a full integrated pest management and xeriscape plan, a street sweeping program, five surface ponds composed of extended detention ponds, a peat/sand filter, and an enhanced (partial wet pond) extended detention pond. There are also subsurface treatment devices that include off-line water quality catch basins conveying to a sand filtration system beneath a parking lot and peat/sand filtering system under an open-space front yard area. Infiltration practices could not be used due to soil conditions. LCRA has acquired grants from the U.S. Environmental Protection Agency to monitor the effectiveness of some of the innovative practices being applied on this project.

The total construction cost associated with the NPS controls on this project was $250,000. This represents about 1.5 percent of the total project cost.

### *Sun City Development*

The Del Webb Corporation is in the planning stages of developing a 2,400-acre active adult community west of Austin, Texas. The project is within the jurisdiction of the Lake Travis NPS Pollution Control Ordinance. Del Webb is presently going through a master plan approval phase with LCRA.

The development is predominantly single-family residential and entails 4,200 single-family homes with recreational amenities. The overall proposed IC for the site is slightly less than 30 percent. The project has incorporated in the preliminary design 60 to 70 structural BMPs to meet the performance requirements of the ordinance. Over 90 percent of the runoff from the development will convey to a structural BMP of some form. The structural practices proposed include extended detention ponds, wet ponds, retention ponds, sedimentation ponds, and infiltration practices. These structural facilities take up 5 percent of the total land area.

In addition, the development includes a roadway system that has vegetated filter strips throughout and grass-lined swales for stormwater conveyance. Commercial areas include a street sweeping program, and areas left as native open space receive credit for pollution reduction as low-maintenance landscapes.

The cost of meeting the performance standards of the ordinance has been estimated by the applicant to be about $1,300 per single-family home. It is quite possible that an economy of scale is realized, as studies before ordinance implementation estimated a per-unit cost of almost twice this amount for developments of similar net density.

## Pros and Cons

The quality of any development management strategy has to be measured on the basis of what it achieves versus the impacts it may create.

### *Strengths of a Technology-Based Approach*

A technology-based approach to control NPS pollution from urbanization has several strengths. The first is the transferability of this approach to other jurisdictions. Creating pollution reduction strategies of this kind can be applied on a city, county, watershed, or statewide basis. The only variables may be in the selection of BMPs that are compatible with a region and the percentage of annual runoff captured based on rainfall patterns.

Implementing land-use restrictions from a density or IC standpoint can be difficult due to public opposition. The technology-based approach gives the landowner the freedom to determine the highest use of the land with consideration given to the increasing costs of providing and maintaining additional BMPs to compensate for dense development. It is theoretically possible for a landowner to use every square inch of land for development purposes if the developer is willing to incur the increased cost of subsurface stormwater treatment or even mechanical treatment.

The standards for achieving compliance with a technology-based ordinance are clear. The approach is simple, with straightforward calculations. This cookbook approach minimizes staffing requirements for review of applications.

Density or IC limitations are a best management practice. More pollution could be discharged, however, from a less dense development with no other BMPs than from a more intense development with BMPs. There is also concern that density controls contribute to urban sprawl, which may result in poorer water quality on a regional basis and may adversely affect air quality through increased vehicular operating time.

Finally, there is no question that implementation of this technology-based practice mitigates some of the water quality impacts associated with urbanization.

### *Weaknesses of a Technology-Based Approach*

The sole use of a technology-based pollution reduction strategy has weaknesses as well. First and foremost is the full reliance on this new technology to maintain a high level of pollution removal over the long term. Recognition of the requirements for maintaining these facilities at their expected performance standards over the long term has yet to occur.

Notwithstanding the urban sprawl issue, there is no question that on a site-specific basis the reduction of IC and maintenance of land in a natural vegetative state are more foolproof means of reducing pollution from that site.

The technology-based approach only considers water quality issues. Land use is at the disposal of the landowner. There are locations where aesthetics, views, and protection of existing vegetation and habitat are equally as important as the quality of water. This ordinance does not directly address these other considerations.

## Conclusion

LCRA considers the NPS ordinance to be an excellent beginning in protecting the quality of the waters of the Highland Lakes and Colorado River. Close to a million people rely on the Highland Lakes for drinking water supply and countless thousands for recreational and aesthetic purposes.

LCRA is committed to evaluating the effectiveness of this ordinance. Depending on the actual development that takes place around the Highland Lakes, the actual pollution removal achieved, and the change in water quality evidenced, more or less restrictive standards or alternate practices may be required. The effectiveness of the ordinance must be analyzed as development takes place to ensure good water quality.

There are limitations in our knowledge of BMPs and of pollution generation from various land uses. The current version of the technical manual is already in need of revision to account for research performed over the last few years. The calculations do not adequately address certain land uses, such as golf courses, nurseries, or parks, due to the low IC yet high maintenance associated with these land uses, particularly as they pertain to pesticides and nutrients.

Finally, it is LCRA's desire to ultimately connect the pollution removal standards of the ordinance to established water quality standards of the receiving waters. There is much work to be performed before a full understanding of the dynamics of the lakes and Colorado River permit us to achieve this goal.

# *New Development Standards in the Puget Sound Basin*

**Peter B. Birch**
**Washington Department of Ecology,**
**Olympia, Washington**

## Abstract

The Puget Sound Water Quality Management Plan (PSWQMP) calls for all counties and cities in the Puget Sound drainage basin to adopt ordinances that require stormwater control for new development and redevelopment. Ordinances were to be adopted by July 1, 1994. The PSWQMP also directed the Washington Department of Ecology to prepare technical guidance and a model ordinance to assist local governments in implementing these standards.

In response, the Department of Ecology has prepared several sets of minimum requirements that are applied based on the type and size of proposed development. These include:

- Simplified erosion and sediment controls and a small parcel erosion and sediment control plan for small developments (under 5,000 $ft^2$ impervious surface), single-family homes, and land-disturbing activities under 1 acre.
- A set of 11 minimum requirements for proposed new development of large parcels (5,000 $ft^2$ impervious surface and greater) and/or land-disturbing activities over 1 acre. The requirements include erosion and sediment control, and source control and treatment best management practices designed to prevent or minimize impacts to receiving waters. A stormwater site plan is also required for this level of development.
- The same 11 requirements apply to large parcels with less than 1 acre of land-disturbing activities except that the small parcel erosion and sediment requirements are substituted for the large parcel erosion and sediment controls.

If redevelopment is proposed, the same minimum requirements apply, subject to a set of thresholds and criteria for applying the minimum requirements to all or part of the site.

## Introduction

Puget Sound, which is located in western Washington State, has been the focus of a comprehensive water quality improvement effort in recent years—especially since documentation of liver tumors in English sole and toxics in sediments and with increasing closures of shellfish beds (1). Initial efforts culminated in 1986, with the publication of the *Puget Sound Water Quality Management Plan* (PSWQMP) and subsequent amendments in 1989 and 1991 (2). In 1991, Puget Sound was listed as an Estuary of National Significance under Section 320 of the federal Clean Water Act.

The section of the PSWQMP that covers stormwater management calls for all counties and cities in the Puget Sound drainage basin to adopt ordinances that require stormwater control for new development and redevelopment by July 1, 1994. The plan also requires all local governments in the basin to adopt operation and maintenance programs for new and existing public and private stormwater systems. Local governments located within census-defined urbanized areas have additional requirements that include:

- Identification and ranking of significant pollutant sources.
- Corrective actions for problem drains.
- A water quality response program.
- Assurance of funding.
- Local coordination.
- Public education.
- Compliance measures.
- An implementation schedule.
- As a last resort in problem areas, retrofitting of control measures.

The PSWQMP also directed the Washington State Department of Ecology (Ecology) to prepare a best management practices (BMPs) technical manual (3) and a program guidance manual containing model ordinances and other supplemental guidance (4) to assist local governments in implementing plan requirements. The guidance prepared for new development and redevelopment consists of several sets of minimum requirements that are applied depending on the type and size of proposed development. In summary, these include:

- Simplified erosion and sediment controls (ESCs) and a small parcel ESC plan for small developments (under 5,000 $ft^2$ impervious surface), detached single-family homes and duplexes, and land-disturbing activities under 1 acre.
- A set of 11 minimum requirements for proposed new development of large parcels (5,000 $ft^2$ impervious surface and greater) and/or land-disturbing activities over 1 acre. The requirements include ESC and source control and treatment BMPs designed to prevent or minimize impacts to receiving waters. A stormwater site plan is also required for this level of development.
- The same 11 requirements apply to large parcels with less than 1 acre of land-disturbing activities except that the small parcel ESC are substituted for the large parcel ESCs.

If redevelopment is proposed, the same minimum requirements apply, subject to a set of thresholds and criteria for applying the minimum requirements to all or part of the site.

The BMP manual that Ecology prepared contains a full description of the minimum requirements and technical guidance on how to meet them. In essence, development sites are to demonstrate compliance with the requirements by preparing and implementing a stormwater site plan that includes an appropriate selection of BMPs from the manual.

Two major components of a stormwater site plan are an ESC plan and a permanent stormwater quality control (PSQC) plan. The ESC plan is intended to be temporary in nature to control pollution generated during the construction and landscaping phase only, primarily erosion and sediment. The PSQC plan is intended to provide permanent BMPs for the control of pollution and other impacts from stormwater runoff after construction is completed. For small sites, this is met by implementing a small parcel erosion and sediment control (SPESC) plan.

Further details of these plans are contained in the *Stormwater Management Manual for the Puget Sound Basin* (3).

The following sections describe the minimum requirements as they apply to local governments in the Puget Sound basin and have been adapted directly from the technical manual (3). The description also includes several associated requirements specific to Washington laws; therefore, some modifications would be needed for application of the minimum requirements to areas outside of Washington. The model ordinance that was prepared as guidance for enacting the minimum requirements is contained in the program guidance manual (4). The full guidance package may be ordered from Ecology by calling (206) 438-7116. The current cost of the technical manual is $24.85 plus postage, and of the program guidance manual is $28.00 plus postage.

## Definitions

The following definitions are useful to the understanding of the minimum requirements:

- *Approved manual:* A technical manual that is substantially equivalent to the *Stormwater Management Manual for the Puget Sound Basin* (3). (The PSWQMP requires all counties and cities located in the Puget Sound basin to adopt a manual that is the same or substantially equivalent to this manual by July 1, 1994.)
- *New development:* Development consisting of land-disturbing activities; structural development, including construction, installation or expansion of a building or other structure; creation of impervious surfaces; Class IV general forest practices that are conversions from timber land to other uses; and subdivision and short subdivision of land as defined in RCW 58.17.020. All other forest practices and commercial agriculture are not considered new development.
- *Redevelopment:* On an already developed site, the creation or addition of impervious surfaces; structural development including construction, installation, or expansion of a building or other structure, and/or replacement of an impervious surface that is not part of a routine maintenance activity; and land-disturbing activities associated with structural or impervious redevelopment.
- *Impervious surface:* A hard surface that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development, and/or a hard surface area that causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development.
- *Land-disturbing activity:* Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land-disturbing activities include, but are not limited to, demolition, construction, clearing, grading, filling, and excavation.
- *Source control BMP:* A BMP that is intended to prevent pollutants from entering stormwater. Examples include covering an activity, controlling erosion,

directing wash water to a sanitary sewer, and altering a practice that results in pollution prevention.

## Exemptions

Commercial agriculture and forest practices regulated under Title 222 WAC, except for Class IV general forest practices that are conversions from timber land to other uses, are exempt from the provisions of the minimum requirements. All other new development is subject to the minimum requirements.

## Small Parcel Minimum Requirements

The following new development shall be required to control erosion and sediment during construction, to permanently stabilize soil exposed during construction, to comply with Small Parcel Requirements 1 through 5, and to prepare a SPESC plan:

- Individual, detached single-family residences and duplexes.
- Creation or addition of less than 5,000 $ft^2$ of impervious surface area.
- Land-disturbing activities of less than 1 acre.

### *Supplemental Guidelines*

The objective of these requirements is to address the cumulative effect of sediment coming from a large number of small sites. The SPESC plan is meant to be temporary in nature to deal with erosion and sediment generated during the construction phase only. Local governments may choose to apply additional permanent, site-specific stormwater controls to small parcels.

### *Small Parcel Requirement 1: Construction Access Route*

Construction vehicle access shall be limited to one route whenever possible. Access points shall be stabilized with quarry spall or crushed rock to minimize the tracking of sediment onto public roads.

### *Small Parcel Requirement 2: Stabilization of Denuded Areas*

All exposed soils shall be stabilized by suitable application of BMPs, including but not limited to sod or other vegetation, plastic covering, mulching, or application of ground base on areas to be paved. All BMPs shall be selected, designed, and maintained in accordance with an approved manual. From October 1 through April 30, no unworked soils shall remain exposed for more than 2 days. From May 1 through September 30, no unworked soils shall remain exposed for more than 7 days.

### *Small Parcel Requirement 3: Protection of Adjacent Properties*

Adjacent properties shall be protected from sediment deposition by appropriate use of vegetative buffer strips, sediment barriers or filters, dikes or mulching, or by a combination of these measures and other appropriate BMPs.

### *Small Parcel Requirement 4: Maintenance*

All ESC BMPs shall be regularly inspected and maintained to ensure continued performance of their intended function.

### *Small Parcel Requirement 5: Other BMPs*

As required by the local plan-approval authority, other appropriate BMPs to mitigate the effects of increased runoff shall be applied.

## Application of Minimum Requirements for New Development and Redevelopment

### *New Development*

All new development that includes the creation or addition of 5,000 $ft^2$ or greater of new impervious surface area and/or land-disturbing activities of 1 acre or greater shall comply with Minimum Requirements 1 through 11 below and be in agreement with a stormwater site plan.

All new development that includes the creation or addition of 5,000 $ft^2$ or more of new impervious surface area and land-disturbing activities of less than 1 acre shall comply with Minimum Requirements 2 through 11 below and the Small Parcel Minimum Requirements listed above. This category of development requires preparation of a stormwater site plan that includes a SPESC plan.

### *Redevelopment*

Where redevelopment of 1 acre or greater occurs, new development Minimum Requirements 1 through 11 apply to that portion of the site that is being redeveloped, and source control BMPs shall be applied to the entire site, including adjoining parcels if they are part of the project.

Where one or more of the following conditions apply, a stormwater site plan shall be prepared that includes a schedule for implementing Minimum Requirements 1 through 11 below to the maximum extent practicable for the entire site, including adjoining parcels if they are part of the project:

- Existing sites greater than 1 acre in size with 50 percent or more impervious surface.
- Sites that discharge to a receiving water that has a documented water quality problem.

- Sites where the need for additional stormwater control measures has been identified through a basin plan or other local planning activities.

Note: An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements that are tailored to a specific basin.)

## *Minimum Requirement 1: Erosion and Sediment Control*

All new development and redevelopment that includes land-disturbing activities of 1 acre or more shall comply with Large Parcel ESC Requirements 1 through 15 below. Compliance shall be demonstrated through implementation of a Large Parcel ESC plan.

All proposed developments where land-disturbing activities 5,000 $ft^2$ and greater but less than 1 acre are planned shall implement the Small Parcel Minimum Requirements above, as well as Minimum Requirements 2 through 11 below.

### Large Parcel ESC Requirement 1: Stabilization and Sediment Trapping

All exposed soils shall be stabilized by suitable application of BMPs. From October 1 to April 30, no unworked soils shall remain exposed for more than 2 days. From May 1 to September 30, no unworked soils shall remain exposed for more than 7 days. Prior to leaving the site, stormwater runoff shall pass through a sediment pond or sediment trap, or other appropriate BMPs shall be employed.

***Supplemental Guidelines.*** This criterion applies both to soils not yet at final grade and soils at final grade. The type of stabilization BMP used may differ depending on the length of time that the soil is to remain unworked.

Soil stabilization refers to BMPs that protect soil from the erosive forces of raindrop impact, flowing water, and wind. Applicable practices include vegetative establishment, mulching, plastic covering, and the early application of gravel base on areas to be paved. Soil stabilization measures should be appropriate for the time of year, site conditions, and estimated duration of use. Soil stockpiles must be stabilized or protected with sediment trapping measures to prevent soil loss, including loss to wind.

These requirements are especially important in areas adjacent to streams, wetlands, or other sensitive or critical areas.

### Large Parcel ESC Requirement 2: Delineated Clearing and Easement Limits

In the field, clearing limits and/or any easements, setbacks, sensitive/critical areas and their buffers, trees, and drainage courses shall be marked.

### Large Parcel ESC Requirement 3: Protection of Adjacent Properties

Properties adjacent to the project site shall be protected from sediment deposition.

***Supplemental Guidelines.*** This may be accomplished by preserving a well-vegetated buffer strip around the lower perimeter of the land disturbance; by installing perimeter controls such as sediment barriers, filters or dikes, or sediment basins; or by using a combination of such measures.

Vegetated buffer strips may be used alone only where runoff in sheet flow is expected. Buffer strips should be at least 25 ft wide. If at any time the vegetated buffer strip alone is found to be ineffective in stopping sediment movement onto adjacent property, additional perimeter controls must be provided.

### Large Parcel ESC Requirement 4: Timing and Stabilization of Sediment Trapping Measures

Sediment ponds and traps, perimeter dikes, sediment barriers, and other BMPs intended to trap sediment on site shall be constructed as a first step in grading. These BMPs shall be functional before land-disturbing activities take place. Earthen structures such as dams, dikes, and diversions shall be seeded and mulched according to the timing indicated in Large Parcel ESC Requirement 1.

### Large Parcel ESC Requirement 5: Cut and Fill Slopes

Cut and fill slopes shall be designed and constructed in a manner that minimizes erosion. In addition, slopes shall be stabilized in accordance with Large Parcel ESC Requirement 1.

***Supplemental Guidelines.*** Consideration should be given to the length and steepness of the slope, the soil type, upslope drainage area, ground-water conditions, and other applicable factors. Slopes that are found to be eroding excessively within 2 years of construction must be provided with additional slope stabilizing measures until the problem is corrected.

### Large Parcel ESC Requirement 6: Controlling Offsite Erosion

Properties and waterways downstream from development sites shall be protected from erosion due to increases in the volume, velocity, and peak flow rate of stormwater runoff from the project site.

### Large Parcel ESC Requirement 7: Stabilization of Temporary Conveyance Channels and Outlets

All temporary onsite conveyance channels shall be designed, constructed, and stabilized to prevent erosion from the expected velocity of flow from a 2-year, 24-hour frequency storm for the developed condition. Stabilization adequate to prevent erosion of outlets, adjacent streambanks, slopes, and downstream reaches shall be provided at the outlets of all conveyance systems.

### Large Parcel ESC Requirement 8: Storm Drain Inlet Protection

All storm drain inlets made operable during construction shall be protected so that stormwater runoff shall not enter the conveyance system without first being filtered or otherwise treated to remove sediment.

### Large Parcel ESC Requirement 9: Underground Utility Construction

The construction of underground utility lines is subject to the following criteria:

- Where feasible, no more than 500 ft of trench shall be opened at one time.
- Where consistent with safety and space considerations, excavated material shall be placed on the uphill side of trenches.
- Trench dewatering devices shall discharge into a sediment trap or sediment pond.

### Large Parcel ESC Requirement 10: Construction Access Routes

Wherever construction vehicle access routes intersect paved roads, provisions must be made to minimize the transport of sediment (mud) onto the paved road. If sediment is transported onto a road surface, the roads shall be cleaned thoroughly at the end of each day. Sediment shall be removed from roads by shoveling or sweeping and shall be transported to a controlled sediment disposal area. Street washing shall be allowed only after sediment is removed in this manner.

### Large Parcel ESC Requirement 11: Removal of Temporary BMPs

All temporary erosion and sediment control BMPs shall be removed within 30 days after final site stabilization is achieved or after the temporary BMPs are no longer needed. Trapped sediment shall be removed or stabilized on site. Disturbed soil areas resulting from removal shall be permanently stabilized.

### Large Parcel ESC Requirement 12: Dewatering Construction Sites

Dewatering devices shall discharge into a sediment trap or sediment pond.

### Large Parcel ESC Requirement 13: Control of Pollutants Other Than Sediment on Construction Sites

All pollutants other than sediment that occur on site during construction shall be handled and disposed of in a manner that does not cause contamination of stormwater.

### Large Parcel ESC Requirement 14: Maintenance

All temporary and permanent erosion and sediment control BMPs shall be maintained and repaired as needed to ensure continued performance of their intended function. All maintenance and repair shall be conducted in accordance with an approved manual.

### Large Parcel ESC Requirement 15: Financial Liability

Performance bonding or other appropriate financial instruments shall be required for all projects to ensure compliance with the approved ESC plan.

## *Minimum Requirement 2: Preservation of Natural Drainage Systems*

Natural drainage patterns shall be maintained and discharges from the site shall occur at the natural location to the maximum extent practicable.

### Supplemental Guidelines

Natural drainage systems provide many water quality benefits and should be preserved to the fullest extent possible. In addition to conveying and attenuating stormwater runoff, these systems are less erosive, provide ground-water recharge, and support important plant and wildlife resources. Effective use of the natural system can maintain environmental and aesthetic attributes of a site as well as be a cost-effective measure to convey stormwater runoff.

Creating new drainage patterns requires more site disturbance and can upset the stream dynamics of the drainage system, thus tending to increase erosion and sedimentation. Creating new discharge points can create significant streambank erosion problems because the receiving water body typically must adjust to the new flows. Newly created drainage patterns seldom, if ever, provide the multiple benefits of natural drainage systems. Where no conveyance system exists at the adjacent downstream property line and the discharge was previously unconcentrated flow or significantly lower concentrated flow, then measures must be taken to prevent downstream impacts. Necessary drainage easements may need to be obtained from downstream property owners.

### *Minimum Requirement 3: Source Control of Pollution*

Source control BMPs shall be applied to all projects to the maximum extent practicable. Source control BMPs shall be selected, designed, and maintained according to an approved manual.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop source control requirements that are tailored to a specific basin; however, in all circumstances, source control BMPs shall be required for all sites.

#### Objective

The intention of source control BMPs is to prevent stormwater from coming in contact with pollutants. A cost-effective means of reducing pollutants in stormwater, source control BMPs should be a first consideration in all projects.

### *Minimum Requirement 4: Runoff Treatment BMPs*

All projects shall provide treatment of stormwater. Treatment BMPs shall be sized to capture and treat the water quality design storm, defined as the 6-month, 24-hour return period storm. The first priority for treatment shall be to infiltrate as much as possible of the water quality design storm, if site conditions are appropriate and ground water quality will not be impaired. Direct discharge of untreated stormwater to ground water can cause serious pollution problems. All treatment BMPs shall be selected, designed, and maintained according to an approved manual.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop runoff treatment requirements that are tailored to a specific basin.

#### Supplemental Guidelines

The water quality design storm (the 6-month, 24-hour design storm, in this instance) is intended to capture more than 90 percent of annual runoff.

Infiltration can provide both treatment of stormwater, through the ability of certain soils to remove pollutants, and volume control of stormwater, by decreasing the amount of water that runs off, to surface water. Infiltration can be very effective at treating stormwater runoff, but soil conditions must be appropriate to achieve effective treatment while not affecting ground-water resources. Methods currently in use, such as direct discharge into dry wells, do not achieve adequate water quality treatment.

### *Minimum Requirement 5: Streambank Erosion Control*

The requirement below applies only to situations where stormwater runoff is discharged directly or indirectly to a stream, and must be met in addition to the requirements in Minimum Requirement 4, Runoff Treatment BMPs.

Stormwater discharges to streams shall control streambank erosion by limiting the peak rate of runoff from individual development sites to 50 percent of the existing condition, 2-year, 24-hour design storm while maintaining the existing condition peak runoff rate for the 10-year, 24-hour and 100-year, 24-hour design storms. As the first priority, streambank erosion control BMPs shall utilize infiltration to the fullest extent practicable, only if site conditions are appropriate and ground-water quality is protected. Streambank erosion control BMPs shall be selected, designed, and maintained according to an approved manual.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop streambank erosion control requirements that are tailored to a specific basin.

#### Supplemental Guidelines

This requirement is intended to reduce the frequency and magnitude of bankfull flow conditions, which are highly erosive and increase dramatically as a result of development. Conventional flood detention practices do not adequately control streambank erosion because only the peak rate of flow is decreased, not the frequency nor duration of bankfull conditions.

Reduction of flows through infiltration decreases streambank erosion and helps to maintain base flow throughout the summer months. Infiltration should only be used, however, where ground-water quality is not threatened by such discharges. The use of an artificial treatment system, such as an aquatard, should be considered in areas with highly permeable soils. Treatment of the water quality design storm must be accomplished before discharge to these soils. If highly permeable soils are present, they should be utilized for streambank erosion control by infiltrating flows greater than the water quality design storm.

### *Minimum Requirement 6: Wetlands*

The requirements below apply only to situations where stormwater discharges directly or indirectly through a conveyance system into a wetland, and must be met in addition to the requirements in Minimum Requirement 4, Runoff Treatment BMPs:

- Stormwater discharges to wetlands must be controlled and treated to the extent necessary to meet state water quality standards.
- Discharges to wetlands shall maintain the hydroperiod and flows of existing site conditions to the extent necessary to protect the characteristic uses of the wetland. Prior to discharging to a wetland, alternative discharge locations shall be evaluated, and natural water storage and infiltration opportunities outside the wetland shall be maximized.
- Created wetlands that are intended to mitigate the loss of wetland acreage, function, and value shall not be designed to also treat stormwater.
- For constructed wetlands to be considered treatment systems, they must be constructed on sites that are not wetlands managed for stormwater treatment. If these systems are not managed and maintained in accordance with an approved manual for a period exceeding 3 years, these systems may no longer be considered constructed wetlands.
- Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements for wetlands that are tailored to a specific basin.

**Objective**

This requirement seeks to ensure that wetlands receive the same level of protection as any other state waters. Wetlands are extremely important natural resources that provide multiple stormwater benefits, including ground-water recharge, flood control, and streambank erosion protection. Development can readily affect wetlands unless careful planning and management are conducted. Stormwater discharges from urban development due to pollutants in the runoff and also due to disruption of natural hydrologic functioning of the wetland system severely degrade wetlands. Changes in water levels and the duration of inundations are of particular concern.

### *Minimum Requirement 7: Water Quality Sensitive Areas*

Where local governments determine that the minimum requirements do not provide adequate protection of water quality sensitive areas, either on site or within the basin, more stringent controls shall be required to protect water quality.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements for water quality sensitive areas that are tailored to a specific basin.

**Supplemental Guidelines**

Water quality sensitive areas are areas that are sensitive to a change in water quality, including but not limited to lakes, ground-water management areas, ground-water special protection areas, sole source aquifers, critical aquifer recharge areas, well head protection areas, closed depressions, fish spawning and rearing habitat, wildlife habitat, and shellfish protection areas. Areas that can cause water quality problems, such as steep or unstable slopes or erosive stream banks, should also be included. Water quality sensitive areas may be identified through jurisdiction-wide inventories, watershed planning processes, local drainage basin planning, and/or on a site-by-site basis.

### *Minimum Requirement 8: Offsite Analysis and Mitigation*

All development projects shall conduct an analysis of offsite water quality impacts resulting from the project and shall mitigate these impacts. The analysis shall extend a minimum of one-fourth of a mile downstream from the project. The existing or potential impacts to be evaluated and mitigated shall include, but not be limited to:

- Excessive sedimentation.
- Streambank erosion.
- Discharges to ground-water contributing or recharge zones.
- Violations of water quality standards.
- Spills and discharges of priority pollutants.

### *Minimum Requirement 9: Basin Planning*

Adopted and implemented watershed-based basin plans may be used to modify any or all of the Minimum Requirements provided that the level of protection for surface or ground water achieved by the basin plan will equal or exceed that which would be achieved by the Minimum Requirements in the absence of a basin plan. Basin plans shall evaluate and include, as necessary, retrofitting of BMPs for existing development and/or redevelopment in order to achieve watershed-wide pollutant reduction goals. Standards developed from basin plans shall not modify any of the above requirements until the basin plan is formally adopted and fully implemented by local government. Basin plans shall be developed according to an approved manual.

**Supplemental Guidelines**

While Minimum Requirements 3 through 7 establish protection standards for individual sites, they do not evaluate the overall pollution impacts and protection opportunities that could exist at the watershed level. For a basin plan to serve as a means of modifying the Minimum Requirements, it must be formally adopted by all jurisdictions that have responsibilities under the basin plan, and construction and regulations called for by the plan must be complete; this is what is meant by an "adopted and implemented" basin plan.

Basin planning provides a mechanism by which the onsite standards can be evaluated and refined based on an analysis of an entire watershed. Basin plans are especially well suited to develop control strategies to address impacts from future development and to correct specific problems whose sources are known or suspected. Basin plans can be effective at addressing both long-term cumulative impacts of pollutant loads and short-term acute impacts of pollutant concentrations, as well as hydrologic impacts to streams and wetlands.

In general, the standards established by basin plans will be site-specific but may be augmented with regional solutions for source control (Minimum Requirement 2) and streambank erosion control (Minimum Requirement 4).

### *Minimum Requirement 10: Operation and Maintenance*

An operation and maintenance schedule shall be provided for all proposed stormwater facilities and BMPs, and the party (or parties) responsible for maintenance and operation shall be identified.

### *Minimum Requirement 11: Financial Liability*

Performance bonding or other appropriate financial instruments shall be required for all projects to ensure compliance with these requirements.

### *Exceptions*

Exceptions to Minimum Requirements 1 through 11 may be granted prior to permit approval and construction. An exception may be granted following a public hearing, provided that a written finding of fact is prepared that addresses the following:

- The exception provides equivalent environmental protection and is in the public interest, and the objectives of safety, function, environmental protection and facility maintenance, based upon sound engineering, are fully met.
- Special physical circumstances or conditions affecting the property are such that strict application of these provisions would deprive the applicant of all reasonable use of the parcel of land in question, and every effort to find creative ways to meet the intent of the minimum standards has been made.
- The granting of the exception will not be detrimental to the public health and welfare, nor injurious to other properties in the vicinity and/or downstream nor to the quality of state waters.
- The exception is the least possible exception that could be granted to comply with the intent of the Minimum Requirements.

**Supplemental Guidelines**

The Plan Approval Authority is encouraged to impose additional or more stringent criteria as appropriate for its area. Additionally, criteria that may be inappropriate or too restrictive for an area may be modified through basin planning (Minimum Requirement 9). Modification of any of the Minimum Requirements that are deemed inappropriate for the site may be done by granting an exception.

The exception procedure is an important element of the plan review and enforcement programs. It is intended to maintain a flexible working relationship between local officials and applicants. Plan Approval Authorities should consider these requests judiciously, keeping in mind both the need of the applicant to maximize cost-effectiveness and the need to protect offsite properties and resources from damage.

## References


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# *Ordinances for the Protection of Surface Water Bodies: Septic Systems, Docks and Other Structures, Wildlife Corridors, Sensitive Aquatic Habitats, Vegetative Buffer Zones, and Bank/Shoreline Stabilization*

**Martin Kelly**
**Southwest Florida Water Management District, Tampa, Florida**
**Nancy Phillips**
**U.S. Environmental Protection Agency, Region 5, Chicago, Illinois**

## Introduction

Local government can substantially protect surface water bodies by enacting and enforcing appropriate ordinances. As part of its Surface Water Improvement and Management (SWIM) Program, the Southwest Florida Water Management District (SWFWMD) in consultation with advisory committees developed a list of seven issues that needed ordinance models. As a result, the SWFWMD outlined and funded a project for model ordinance development. The scope of the project included preparing model ordinance language to address seven specific issues, drafting individual papers addressing the ecological and legal significance of each issue, and developing a decision model for local government planners to use in determining the applicability or need for ordinance adoption. The private consulting firm Henigar and Ray, Inc., of Crystal River, Florida, developed under contract the model ordinances, issue papers, and decision model.

This paper highlights the results of and recommendations for ordinances addressing six of the seven project issues:

- Placement and maintenance of individual septic systems
- Regulation of docks and other appurtenance structures
- Establishment of wildlife corridors
- Protection of environmentally sensitive habitats
- Vegetative buffer zones
- Erosion control and bank stabilization

The seventh issue, "Stormwater Management and Treatment," is covered in other papers in this publication.

Because any ordinance is likely to face challenges, often from a number of opposing camps, issue papers were drafted to support an ecologically and legally defensible argument. While legal information contained in the detailed issue papers focuses on the Florida experience, the ecological arguments are valid over a much larger geographic area.

It is not possible to consider in detail the products of this project; however, this paper attempts to transfer the flavor and scope of information available on each of the issues. The paper provides an overview on the need/justification for a particular ordinance, mentions some of the technical issues that should be considered, and recommends necessary components of a viable ordinance. (The U.S. Environmental Protection Agency [EPA] is currently condensing the body of this work [1].)

## Project History

The State of Florida passed the SWIM Act in 1987 establishing a program similar to the Clean Lakes Program but encompassing all surface waters (i.e., estuaries, rivers, springs, lakes, and swamps [2]). The Act mandated that each of the state's five water management districts develop a list of priority water bodies and begin developing management plans for each of them. Once a management plan received approval, monies from the SWIM Trust Fund could help implement projects outlined in the specific management plan for each water body.

During plan development for a number of water bodies, several advisory committees suggested that drafting and enacting ordinances at the local government level (municipality or county), particularly with regard to land development issues, could do much to protect water bodies from degradation. Such ordinances would be proactive in that they would avoid or minimize anticipated deleterious impacts. SWIM staff at the SWFWMD in consultation with various members of advisory committees identified the seven issues that required model ordinances.

Although passage of the SWIM Act gave the state's water management districts no new regulatory authority, the SWFWMD felt it was appropriate to develop model ordinances for consideration by local governments. Because enactment of ordinances that affect development are likely to invoke challenges, SWFWMD deemed it necessary not only to develop model ordinance language but also to develop "issue papers" detailing the ecological justifications for a given ordinance. Issue papers would also review similar ordinances already enacted in Florida and elsewhere (i.e., establish precedence) and consider the legality of enacting a particular ordinance. Henigar and Ray, Inc., employed the appropriate technical and legal authorities to draft the issue papers and ordinance language. The project resulted in a series of seven issue papers, five model ordinances, a decision model (planning document), and a report summarizing "The Law of Surface Water Management in Florida."

## Placement and Maintenance of Individual Septic Systems (3)

Almost invariably when potential sources of pollutants to a water body are discussed, the topic of septic tanks arises. Many people assume that their septic systems are operating effectively simply because failure is not obvious (i.e., blocked plumbing, standing water over the drain field). As Brown (4) has pointed out, a system's technical failure (the inability to effectively process the waste) goes unnoticed; as long as the homeowner is not inconvenienced, the system usually remains unrepaired.

Septic systems can fail for two basic reasons: poor design or poor maintenance. Design includes not only the tank and drain field layout, but also the soils and hydrologic character of the site. Maintenance implies a periodic check and cleaning of the tank and possibly the drain field, and a consideration of the substances discharged to the system.

Effective treatment in the drain field requires soils of the proper permeability. For example, soils that are too permeable permit the tank effluent to travel too rapidly away from the drain field and do not allow for proper biologic treatment in the biomat. Alternately, impermeable soils become clogged with effluent, causing lateral or upward seepage. In the latter case, the homeowner may be inconvenienced, but in the former the owner may assume everything is working fine.

Soil absorption fields must lie above the surficial water table. If not, the system will cease to function effectively. An unsaturated zone ensures a desirable effluent velocity away from the drain field and good aeration in the zone where aerobic decomposition should occur. A typical onsite sewage disposal system (OSDS) ordinance might require, for example, a minimum of at least 24 in. between the bottom of the absorption (drain) field and the seasonal high water table. Virtually every Health and Rehabilitative Services (HRS) worker in Florida who is familiar with OSDS permitting can cite at least one example of a drain field totally submersed underwater during Florida's summer wet season.

Design, siting, and construction of a proper OSDS do not ensure proper long-term operation. Maintenance is absolutely necessary. The typical OSDS owner is often unknowledgeable regarding proper OSDS maintenance. In fact, many owners are unaware that septic tanks should be pumped out periodically to remove accumulated septage. Ayers and Associates (5) reported that it is "relatively common for homeowners to have never serviced the septic tank during their occupancy in the home."

Water conservation within the home can reduce waste flow and attendant pollutant load. This extends the life of the drain field, reduces system failures, and saves money by increasing the time between needed pumpouts. Low-flow toilets and shower heads and "graywater" reuse are examples of water conservation measures that can reduce potable water consumption. Siegrist (6) reported that eliminating the use of garbage disposals in connection with OSDSs could decrease the total suspended solids load by as much as 37 percent.

A host of findings in the literature support the development of ordinances to regulate septic systems. Interestingly, Cooper and Rezek (7) found that most of the heavy metals in the typical OSDS effluent stream originated from pigments used in cosmetics. In addition, EPA (8) found that compounds from septic tank cleaning solvents (i.e., methylene chloride and trichloroethane) actually hinder septic tank operation by killing bacteria that promote decomposition. Bicki et al. (9) concluded that nitrate-nitrogen contamination of ground water by OSDSs is a national problem and that high concentrations in many areas pose a health risk to infants. Yates and Yates (10) documented the extreme distances that certain microorganisms can move and remain viable. Certain viruses, because of their small size and long survival times, were found as far as a mile from their source in karst areas, an especially significant subsurface geologic feature in Florida.

Certain authors have also correlated septic tank density (allowable units per acre) with ground-water contamination (10, 11). Recommended acceptable densities vary greatly, with densities being a function of soils, depth to water table, and distance from surface water bodies.

Any entity considering a local ordinance to regulate septic tanks can, based on the literature, consider several options that might be more restrictive (protective) than existing regulations. These can relate to soils, depth to ground water, densities, and distance to surface water. These options may take the form of pumpout and inspection requirements, alternative septic systems, prohibitions (e.g., no garbage disposals), and even “moratoriums” in already contaminated or totally unsuitable areas.

## Regulation of Docks and Appurtenance Structures (12)

Czerwinski and McPherson (12) thoroughly defined the various classes of docks and marinas (e.g., private single family, multislip residential, and commercial marinas). The intended use and size of a facility are important from both an impact and a regulatory standpoint, but space does not allow us to consider these in detail; the interested reader should consult the original document or the condensation being prepared by Simpson (1). To be effective, an ordinance must clearly define what is to be regulated. It is advantageous to include definitions within the body of the ordinance to avoid ambiguity that could seriously limit ordinance effectiveness.

The potential need to adopt an ordinance on a local level may be determined by considering projected increases in the number of registered boats in an area. As an example, in Florida there are approximately 48 boats per thousand residents. This reflects a 300-percent increase in the number of registered boats since 1964. Florida ranks fourth nationally in the number of registered boats, and the Florida Department of Natural Resources has projected a 48-percent increase to 712,349 boats by the year 2005 (13).

Environmental impacts associated with docks and appurtenance structures (e.g., boathouses, gazebos, and diving platforms) can be direct or indirect. Direct impacts relate to areas adjacent to and covered by these structures, and would typically include the transitional zone between the upland, wetland, and open water. The “littoral zones provide many valuable ecological functions, including flood storage, erosion and sedimentation control, filtration of surface water runoff, and essential habitat for flora and fauna” (12). Indirect effects, which are due to the attendant use of these structures, include effects attributable to outboard exhausts, fuel spills, sanitation facilities, and prop scour.

When regulating these structures, the actual construction materials should be considered. The list is long and varied. Wood is probably the most widely used material, particularly for single-family facilities. Whereas untreated wood is no match for the aquatic environment, chemically treated wood may last for 15 to 20 years without replacement. Chemicals used in treatment processes include ammoniacal copper arsenate (ACA), chromated copper arsenate (CCA), creosote-coal tar (CCT), acid copper chromate (ACC), chromated zinc chloride (CZC), fluorochrome arsenate phenol (FCAP), pentachlorophenol (which provides a clean, paintable surface), and creosote-petroleum solutions (14). “Although the pertinent regulatory agencies . . . test and register these substances as generally safe for use,” Czerwinski and McPherson (12) concluded that “research conducted in preparation of this paper revealed little data or information on the biologic effects of wood preservatives on (nontarget) aquatic and marine organisms.”

Other construction materials include steel, aluminum, reinforced concrete, fiberglass, and polyvinyl chloride (PVC). Styrofoam (expanded bead foam polystyrene) is still common in floating docks, although it may not be the most suitable floatation material available today. Unfortunately, bead foam polystyrene tends to break up easily, has a long life, and may be ingested by and be harmful to wildlife. In addition, chlorofluorocarbons are used in the manufacturing process. Safer but more expensive alternatives such as petroleum-resistant polystyrene and sealed solid (as opposed to extruded) foam are available.

Docks and appurtenance structures should not interfere with navigation. In Florida, for example, a dock is not considered a navigation hazard if it does not exceed 20 to 25 percent of the distance across the water body, is limited to the minimum distance necessary to provide reasonable access to navigable waters (which is generally defined to be approximately 4 ft below mean or ordinary low water), and does not infringe upon the main navigational channel or upon the riparian rights of adjacent property owners. For safety reasons, docks may be required to be fitted with navigational aids (e.g., lights or reflectors).

Turbidity and sedimentation problems can result from construction activities. Such impacts, however, are likely to be small compared with other activities unless the construction requires a large area and considerable time, as might be the case with commercial marinas. Florida water quality regulations, however, do not allow turbidity in excess of 29 nephelometric turbidity units above background in any case, and regulatory agencies may require the installation of turbidity screens or other protective barriers. Turbidity problems more likely arise indirectly from effects such as prop scour as boats make use of docking facilities.

Shading of the water column and the littoral shelf can also affect the environment. Shading may not be a problem in areas where a tree canopy already exists, but obviously it can affect areas previously unshaded. Czerwinski and McPherson (12), however, cite no scientific studies on the direct effects of shading by docks or appurtenance structures. Employing some simple siting and design criteria can avoid or at least lessen any potential detrimental effects. Suggestions include:

- Siting in areas already shaded or in areas low in light-dependent resources requiring protection.
- Elevating structures in areas high in light-dependent resources (e.g., grass beds).
- Substantially elevating accessways, boardwalks, or other appurtenance structures that are not as water dependent.
- Spacing of planking to allow sunlight to penetrate (e.g., leaving 1-in. gaps between boards).

Another obvious effect is that installation of docks and attendant structures directly alters the shoreline. In Florida, for example, a lakefront resident desiring access may remove a 25-ft wide band of vegetation to open water without a permit and without revegetating the area. These areas frequently suffer clearing in association with docks and similar structures. Depending on lot size, then, it is conceivable that residents may remove as much as half of the shoreline vegetation for access without needing a permit.

Fortunately regulatory agencies may have the ability to consider the cumulative impacts of projects in deciding whether to issue a permit. Florida's Department of Environmental Regulation, by virtue of its "dredge and fill" responsibilities, requires a permit to construct a dock or other structures that affect wetlands. "Therefore, these agencies have the authority to review, suggest alternatives ... or deny projects based upon the 'foreseeable,' future cumulative impacts. However, the ability to deny a project based upon future, anticipated cumulative impacts can be subjective and is cautiously exercised due to the potential for legal challenge. This is most likely to be a supportable factor in project review when specific endangered species concerns are at issue" (12).

Of course, not all shoreline changes are detrimental. For example, a dock could expose previously densely vegetated areas, thus creating open sandy areas that can provide valuable fish bedding areas. Docks and related structures can also provide cover or serve as substrate for aquatic organisms.

Most indirect environmental effects ascribable to docks and appurtenance structures result from recreational boating activity. These include potential effects from outboard motor exhaust contaminants, prop dredging, sanitation devices, fuel and oil spills, and antifouling boat paints. Rather than consider most boating impacts in detail here, the reader can refer to the review by Wagner (15).

Antifouling paints, which prevent fouling of hulls by marine organisms (e.g., barnacles), pose an unusual problem. Traditional coatings contain lead, copper, and organotin compounds. For antifouling, the organotins are especially effective because they continuously release active ingredients into the water. One of the organotins, tributyltin (TBT), has gained recent notoriety. EPA, due to the results of documented acute and chronic effects, has proposed maximum concentrations of 26 and 10 parts per trillion in fresh and marine water, respectively, for the protection of fish and other aquatic organisms. They have further proposed restricting sales of TBT to certified commercial pesticide applicators for use only on vessels greater than 65 ft in length.

The concepts of cumulative impacts and carrying capacity are important considerations. They are, however, difficult to implement with respect to docks and other water-dependent structures. Czerwinski and McPherson (12) did not cite studies that defined how one might set scientifically defensible limits. This is clearly an area needing research. Although often discussed and debated, regulation is difficult on this premise due to the lack of quantifiable data.

Docks and water-dependent structures should be located so as to minimize adverse environmental impacts. Where possible, authorities should encourage multislip facilities over the use of many individual docks. Approval of docks should include criteria for preserving a portion of the remaining unaffected shoreline, such as conservation easements or shoreline buffers. Another helpful measure may be to consider construction of boat ramps in lieu of docks; a careful analysis, however, is necessary to ensure consideration of increases in boat traffic and of the need for appropriate provisions to limit ramp usage.

## The Need for, Rationale for, and Implementation of Wildlife Dispersal Corridors (16)

The SWIM Act was careful to stress the state's desire to restore or preserve the natural systems associated with its surface water bodies as well as its water quality. There is a growing awareness among resource managers that preserving fauna and flora involves strategies that stretch beyond watershed and governmental boundaries. The need to implement a system of faunal corridors may be the hardest issue to grasp in this paper, and it is doubtful that the authors can do more than introduce the topic. In fact, to a resource manager with a background in water-related issues, the issue paper developed by Harris (16) may appear exhaustive and rhetorical and is almost certain to pose unfamiliar questions and problems.

Model ordinance language proposed with regard to this topic (i.e., faunal corridors) was unlike the others developed. Accordingly, we have referred to the work as an "article" rather than an ordinance. The proposed article

> serves only to provide a means by which the boundaries and natural amenities of a WCSD [Wildlife Corridor Special District], as well as nonnatural

characteristics and associated implications, can be identified. Once the WCSD has been identified, and a strategy for its protection and management developed, an ordinance is required to actually create the WCSD. Due to the many site-specific characteristics involved in defining the areal extent, physical characteristics and management implications of the WCSD, such an ordinance is impossible to develop in a "generic" form that would be applicable to all jurisdictions and geographic areas in which the ordinance potentially would be used. This Article does, however, provide general guidelines for the creation of a WCSD, while also providing a method by which virtually all information needed for a WCSD-creation ordinance can be collected.

Harris (16) suggested that it is not possible to appreciate the need for implementing a system for faunal movement corridors without first comprehending three major issues:

> "1. Throughout most of North American history, humans and their developments have occurred as localized entities in an expansive and interconnected matrix of undeveloped natural ecosystems; now, it is the natural systems that occur as localized entities in a matrix of human development.
>
> "2. The second issue is the current biological diversity crisis. Without a keen awareness of the breadth of the dimensions and rapidity at which biological diversity (biodiversity) is currently being eroded there can be no grasp of the gravity of the remedial actions that must be taken.
>
> "3. The third critical issue concerns the need of plants and animals to move; without carefully weighing the value of plant and animal movement corridors against other alternative conservation actions it is not possible to achieve balance and perspective in approaching these concerns."

Harris (16) makes a semantical distinction between the terms "wildlife" and "faunal," with faunal relating specifically to native animal species. Although it is important to appreciate how others may apply these terms, this paper applies them more or less interchangeably.

The need for implementing a system of faunal corridors is recent. Depending on the degree of development in an area, the need becomes more pressing in some areas than others. The need appears great in Florida. Historically, human developments have occurred as islands in a matrix of natural ecological communities; now, however, the pattern has changed, with unaltered natural communities occurring as islands in a predominately human-altered environment.

As noted by Harris (16), "a confusing paradox to many is the fact that habitat fragmentation may enhance local wildlife diversity while simultaneously reducing native biotic diversity at a somewhat larger scale." Harris explains this paradox is due to the action of the following mechanisms:

- Populations lose genetic integrity due to being sequestered within patches (i.e., islands).
- "Forest-interior" and "area-sensitive" species that cannot exist within small habitat patches are lost.
- Weedy species that are characteristic of disturbed environments increase in abundance.
- Important ecological processes are disrupted.

Geographic separation of populations and gene pools can, over geologic time, lead to new species. Spatial separation, however, which creates small isolated populations preventing gene flow, can lead to elimination of populations and even extinction of species. As an example, Harris (16) cites the following statistics on the degree of inbreeding depression that has already occurred in isolated populations of the Florida panther:

- Of all the Florida panthers known to exist in the wild today, less than a dozen are reproductively unrelated.
- The percentage of infertile spermatozoa in all male Florida panthers examined in recent years exceeds 90 percent.
- Of all the male Florida panthers examined, only about 50 percent have two distended testicles, and "it remains a matter of speculation if or when the highly inbred males might exhibit bilateral cryptorchidism and be unable to reproduce at all."

Roads are a significant fragmenting force because, unlike the passive fragmentation caused by areas such as farm fields, roads possess an active mortality-causing force—the associated traffic. Lalo (17) has estimated that nationally trucks and automobiles kill as many as 100 million vertebrates annually. Over 146,000 deer were killed on U.S. highways in 1974 (18). Adams and Geis (19) and Voorhees and Cassel (20) present statistics showing that within the contiguous 48 states and within individual states, the amount of land set aside in the form of national parks, wildlife refuges, and game management areas is smaller than the land that roads and rail right-of-ways occupy. Vehicles, including boats, represent one of the most significant sources of mortality for all of Florida's large threatened, rare, and endangered vertebrates. These include the panther, key deer, black bear, eagle, crocodile, and manatee. Data cited by Harris (16) even suggest that the number of road kills increases in direct proportion to vehicle speed.

Roads create barriers in several ways:

- They alter light, wind, temperature, humidity, evaporation rates, and noise level as they create a different microclimate in and near the right-of-ways.
- Exhaust fumes cause avoidance by some species, and heavy metals accumulate in those that occur adjacent to roadways (21).
- Pesticides used to maintain right-of-ways affect non-target plants and animals as well.

Right-of-ways have led to the creation of a different type of ecological community. Harris (16) cites numerous examples of opportunistic predators that “run roadsides” in search of prey.

Over the last 20 years, there has been an increasing realization that habitat fragments, even relatively large fragments, are not adequate protection for many species; if these species are to be protected, corridors must connect these habitat fragments. Simple green belts are not sufficient because corridors of non-native habitat welcome “weedy” species. Interconnecting corridors must be consistent with the habitats they are connecting to avoid “edge effects”; the wrong types of corridors could conceivably hasten the spread of exotic or weedy species. Currently in Florida, considerable funds are being spent to “Save Our Rivers” and protect the water quality of streams. Careful consideration and planning could ensure that these programs accomplish a dual function by protecting our biological diversity as well. As Harris (16) states, “When sufficiently wide, streamside management zones serve as critically important habitat for many rare and endangered native species. But unless the streamside zones connect larger tracts of habitat or protected areas they may function simply as long narrow fragments of habitat.”

Corridors are necessary to keep small fragmented populations from being expatriated, to preserve biodiversity, and ultimately to allow populations to adapt to major climatic and geologic changes. Because of the geographic scope involved, corridors are an issue that will require cooperation and coordination between local, regional, and state governments and agencies.

## Protecting Environmentally Sensitive Aquatic Habitats (22)

Aquatic habitats include lakes, rivers, streams, estuaries and bays, springs, and wetlands. These habitat areas are typically subject to a variety of differing agency jurisdictions. Quite commonly, though, ordinances developed at the local level protect wetlands (including marshes, swamps, bogs, ponds, and wet prairies). Local wetland resource areas promote the local quality of life as well as the quality of the environment. The advantages include hydrologic functions (flood control, runoff velocity control, ground-water and surface-water recharge), water quality benefits (erosion and sedimentation control and removal of pollutants such as nutrients and heavy metals), and wildlife habitat benefits (food source, breeding, nesting, spawning, and wildlife protection) (23).

When wetlands are allowed to remain in their natural state, they maximize multiple benefits and achieve ecological stability. Anthropogenic changes, however, can affect the natural function and resultant benefits of the wetland, such as change the quality of the water entering the wetland, the hydrologic cycle of the wetland, and the physical structure of the wetland (24). Several sources can affect the quality of water entering the wetland, including point and nonpoint pollution, nutrient enrichment, and sedimentation (25). The hydrologic cycle of the wetland can be disrupted by well pumping, channelization, sedimentation, upstream diversions, increased surface flows, and decreased ground-water base flows. In addition, filling, dredging, and channelization can affect the physical structure of the wetland (26).

By identifying the sources of impacts to these valuable areas, one can begin to develop the necessary elements of a local ordinance that would help to restore and maintain ecological integrity. An ordinance should address the wetland system from a holistic perspective, not as isolated areas. Some recommendations for a wetlands protection ordinance include the following:

- Consider individual and cumulative impacts on aquatic habitats from anthropogenic alterations. Environmentally sensitive systems can degrade from the accumulation effect of many individual human activities (27).
- Develop specific performance standards. Performance standards will allow local governments to use environmentally sensitive lands in a manner that minimizes negative impacts (28).
- Develop financial incentives that encourage local property owners to protect aquatic habitats. If environmentally sensitive areas are to be protected through long-term management of private lands, land owners must be compensated accordingly (29).
- Develop mechanisms by which local government facilitates the property owner’s efforts to protect aquatic habitats. If proper channels exist for conservation easements and reduced tax assessments, voluntary efforts to protect environmentally sensitive areas may increase (29).
- Coordinate state and federal permitting processes. Coordination at the local level will ensure compliance with all requirements that serve to protect, enhance, or restore environmentally sensitive areas.

- Identify state and federally exempted activities that contribute to the degradation of aquatic habitat, and regulate those activities locally.
- Develop an appropriate definition of aquatic habitat. An adopted definition will define the areas of jurisdiction for local, state, and federal regulations; few definitions, however, adequately describe all environmentally sensitive areas (29). Local definitions can provide greater protection for those areas not adequately protected by state or federal regulations.
- Develop a long-term plan for the protection of aquatic resource areas, and develop management objectives that will provide the desired level of protection.
- Provide for local enforcement. Taking responsibility for local environmentally sensitive areas ensures maximum protection.

Along with the above requirements, additional elements can be considered:

- Create a mechanism to develop site-specific upland buffer zones.
- Create a mechanism to implement fixed-distance upland buffer zones.
- Create a mechanism to implement no construction/no disturbance zones.
- Allow for restoration of disturbed areas at ratios greater than 1:1.
- Incorporate endangered, threatened, and special-concern species into upland buffer zone consideration.
- Encourage the use of creative site planning to preserve and protect sensitive aquatic habitats.

## Vegetative Buffer Zones (30)

A transition zone is an area between a water body (e.g., wetland, lake, river) and upland areas. The area of land that a transition zone occupies varies and is greatly influenced by topography. In areas of major topographic changes, the transition zone tends to be small (1 to 2 ft). In areas where topographic changes are slight, the transition zone tends to increase in size substantially (30 to 50 ft).

Vegetative transition zones provide multiple benefits to the surrounding area. First, they are ecologically complex, as the assemblage of plants and animals can be characteristic of the nearby water body as well as the upland area. Within these areas, substantial ecological diversity can occur (31-33). Second, transition zones help maintain a balanced hydrologic cycle by retarding the flow of surface runoff volumes through absorption and by allowing for infiltration into the ground water. Vegetative transition zones also play a major role in the maintenance of the quality of the nearby water resource. Processes such as deposition, absorption, and transformation help remove pollutants such as sediment, phosphorus, nitrogen, and heavy metals from overland flows. Also, when vegetation is present, it tends to reduce the temperature of storm flows, thereby maintaining water body temperatures (34, 35).

When activities related to urbanization disturb vegetative transition zones, the benefits realized can be diminished or even lost. With the removal of the complex ecological area, habitat values decrease, resulting in a loss of species diversity and richness (36, 37). Urbanization activities can also disrupt the hydrologic balance of the nearby water bodies. Typically, surface water hydrology changes to reflect the increase in the volume and rate of surface flows. This causes increased streambank erosion adjacent to the disturbed area as well as downstream. Streambank erosion reduces water clarity, destroys benthic habitat, interferes with aquatic plant transpiration processes, and reduces stream storage capacity. Removal of vegetative transition zones affects ground-water flow by reducing the overall infiltration rate of surface water to ground water. The decrease in surface water recharge can affect the hydroperiod of nearby wetlands, which are heavily dependant on ground-water discharge, and nearby stream base flows. Removing transition zones also affects water quality by allowing pollutants to enter the watercourse untreated. One of the most obvious water quality impacts is the increase in sedimentation to the receiving waters (30).

Because vegetative transition areas provide such valuable ecological benefits, protection measures need to be implemented to ensure their preservation. The size of these areas, however, tends to be site specific and requires individualized management approaches. Therefore, local ordinances are the most effective and adaptive tool to facilitate preservation.

In developing an ordinance for vegetative transition zones, efforts should maximize the benefits to wildlife, habitat, hydrology, and water quality. Methodologies have been developed to "engineer" vegetative transition areas in a supportable, defensible manner. In general, the recommendations for vegetative transition areas are:

- Minimize disturbances of vegetative transition zone when possible through the use of site fingerprinting. Limiting the extent of disturbance will greatly reduce the potential of negative water quality impacts.
- Develop local requirements for "no-build" and "no-disturbance" zones. Protective buffer zones can be implemented in such a way to allow for construction while minimizing the impact of development.
- Encourage alternative land use planning that can protect vegetative transition areas. Planning techniques

are valuable tools that can afford long-term protection and management of vegetative areas.

- Develop criteria for vegetative transition areas based on defensible procedures. This is an important step that will implement vegetation protection measures in a nonbiased manner. Based on identifiable and scientific procedures, arguments can be made for successful long-term implementation.

Examples of recommendations for vegetative transition follow:

- Area size of 30 to 550 ft may be necessary when ground-water drawdown is an issue (using surficial aquifer data and structure drawdown calculations).
- Area size of 75 ft for coarse sand, 200 ft for fine sand, and 450 ft for silty soils should be considered to protect water quality (utilizing Technical Release [TR] 55, local soils data, and soil deposition formula).
- Area size of 322 ft for fresh and saltwater marshes, 550 ft for hardwood swamps, and 732 ft for bordering sandhill communities to protect wildlife habitat (based on indicator species and 50 percent other present species).

## Providing for Erosion Control and Bank/Shoreline Stabilization (38)

Banks and shorelines are those areas that occur along streams, lakes, ponds, rivers, wetlands, and estuaries where water meets land. The topography of banks and shorelines can range from very steep to very gradual. These areas can be considered a subset of the vegetative transition areas.

Banks and shorelines provide many benefits to the environment, including prevention of erosion, storage and attenuation of runoff, and provision of valuable habitat for fish and wildlife (39). Stabilization, which prevents erosion, occurs below the water line via root systems, as well as above the water line through absorption of raindrop energy and overland flow velocity. Both physical characteristics and stability of the bank and/or shoreline accomplish the storage and attenuation of runoff. The provision of habitat is also accomplished through physical stability and the unique physical characteristics of the bank and/or shoreline. Often, ecological zones will be apparent and consistent with the shoreline, and provide special habitat for various plant and animal species (29).

As water bodies continue to support human activities both on and near the water, impacts will occur to the bank and shoreline area. Flows of increased water movement from activities such as boating can cause erosion, damage to vegetation, and increased turbidity in aquatic habitat areas (40). Urbanization commonly results in a change in the surface water hydrology, increasing storm volumes and rates of discharge. This movement of storm flows through water channels tends to erode and undercut banks and shorelines over time. The resultant erosion reduces water quality through increased turbidity as well as destruction of existing bank and shoreline habitat and smothering of downstream habitat areas (29, 41).

Bank and shoreline stabilization is an important element necessary to protect multiple ecological benefits. Ordinances that recognize this can be developed to address local management needs. Bank and shoreline stabilization typically should include an array of approaches as outlined below:

- Promote nonstructural methods such as revegetation and preservation of vegetation because they are an inexpensive and beneficial approach. Studies have shown that nonstructural practices can provide multiple benefits to bank and shoreline areas where implemented. Also, construction costs are substantially lower than traditional structural methods (41, 42).
- Limit use of structural methods to when erosive forces are significant. Public perceptions and aesthetics have led to the construction of structural methods in areas where nonstructural methods could have worked. Structural methods should be the last option when addressing bank or shoreline erosion.
- Develop an appropriate definition for banks and shorelines. Good definitions provide jurisdictional boundaries to those attempting to implement protection measures.
- Develop a long-term comprehensive plan for the protection of banks and shorelines. Comprehensive planning will ensure that bank areas and shorelines remain in their natural state.

Additional recommendations for the protection and preservation of banks and shorelines can include:

- Meet environmental goals through shoreline stabilization regulations that are performance based (not numerical).
- Allow for flexibility to integrate structural and nonstructural methods.
- Address instability caused by water-based and land-based activities.
- Develop financial incentives that encourage the local property owner to employ nonstructural techniques.
- Prohibit the use of noxious plants while encouraging the use of native plant species.
- Provide design standards.

## Conclusion

While much of the information considered in this paper was gathered with a focus on Florida, we feel it can be extrapolated to other states. Although ordinances can be enacted to address singular issues, it is better to develop a more comprehensive approach to development review. This kind of approach can eliminate potential duplicity while maximizing environmental benefit. The issues addressed above range widely, but environmental integrity and preservation are common themes. Enactment of an ordinance rarely occurs without challenge, but its chance of passage can only be increased by a scientifically justifiable and legally defensible argument.

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# *Urban Runoff Pollution Prevention and Control Planning: San Francisco Bay Experiences*

**Thomas E. Mumley**
**California Regional Water Quality Control Board, San Francisco Bay Region**
**Oakland, California**

## Abstract

The California Regional Water Quality Control Board, San Francisco Bay Region, began a program for control of urban runoff pollution in 1987. The initial focus of the program has been on the municipalities in Santa Clara and Alameda counties. Both county programs followed a similar methodology consisting of the following steps: establish program goals and framework; compile existing information; assess water quality problems through collection and analysis of data and modeling of pollutant loads; identify, screen, and select appropriate control measures; and establish a plan for implementation. The Alameda program had the benefit of lagging behind the Santa Clara program by about 1 year. This provided the Alameda program with the advantage of streamlining efforts based on the successes of the Santa Clara program.

The experiences of these programs provide even further insight into streamlining and optimizing the planning process. Understanding the benefits of each step of the planning process enables a municipality to focus limited resources on the more critical factors affecting development of an implementation plan. For example, a municipality may weigh the cost of obtaining new data to make more informed decisions with the risk associated with making assumptions in the selection and implementation of control measures in lieu of data acquisition. Lessons learned to date are now being utilized by other municipalities in the San Francisco Bay area, leading towards timely and cost-effective development of urban runoff management programs.

## Introduction

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), is the state water pollution control agency responsible for protecting the beneficial uses of San Francisco Bay and its tributaries. San Francisco Bay is a highly urbanized estuary and, as such, receives significant loads of pollutants through discharges of urban runoff. The Regional Board began a program for control of urban runoff on a watershed basis in 1987. The goals of the Regional Board's program are to protect beneficial uses through attainment of water quality standards in waters of the region and to reduce pollutants in urban runoff to the maximum extent practicable. These two goals reflect a dual water quality and technology based approach and serve to integrate specific regulatory programs such as the stormwater National Pollutant Discharge Elimination System (NPDES) permit program. The Regional Board has promoted an areawide approach, with the initial focus of the program on the municipalities in Santa Clara and Alameda counties. This has led to the development of a pseudowatershed-based program in each county.

The Regional Board program goals also serve as the primary goals of the specific municipal urban runoff programs. We recognize, however, that attainment of such broadly defined goals can only be achieved through a carefully planned strategy. Both county programs followed a similar strategy consisting of the following steps: establish program goals and framework; compile existing information; assess water quality problems through collection and analysis of data and modeling of pollutant loads; identify, screen, and select appropriate control measures; and establish a plan for implementation. Normally, such steps would proceed in sequence. With an understanding of the purpose of each step and its relation to the others, however, one may consider a nonsequential or parallel process. The Alameda program commenced approximately 1 year after the Santa Clara program and had the advantage of being able to streamline efforts based on the successes of the Santa Clara program. The lessons learned by the Santa Clara and Alameda programs provide valuable insight for optimizing the planning process.

The Regional Board served as a facilitator in the development of both the programs, but it has been the cooperative, proactive approach of the municipalities that has resulted in the development of a technically sound and cost-effective urban runoff program. The following discussion reflects the experiences and accomplishments of the Regional Board and the Santa Clara and Alameda programs.

## Planning Strategy Steps

### *Program Framework*

Development of an effective urban runoff management program first requires an effective framework that involves participation by all pertinent municipal agencies. Initiation of both county programs began with creation of a task force with participants from city and county public works, city and county planning, sewage treatment works, and flood control. The task force served as a forum for communication among the involved agencies, as well as an oversight body to track all the steps of the planning process. Specific activities included establishment of program goals, development of a memorandum of agreement among the participating agencies, designation of a lead agency for anticipated contracts, and development of a work plan for the planning strategy. The work plan identified the specific tasks and timelines of the planning strategy, identified responsible parties and consultant needs, and identified the financial resources necessary for completion of the planning process.

Both programs relied on extensive consulting services for preparation of the planning process work plan and implementation of the planning tasks. Although the programs benefited from this approach, an overreliance on outside help may result in insufficient awareness and expertise within the ultimate implementation agencies of the urban runoff management program. An effective approach should use new or existing municipal personnel as much as possible throughout the planning process. Outside services may play a valuable role, but they will be most effective when specific technical or other needs have been identified and communication and cross training with municipal staff are provided.

### *Compilation of Existing Information*

Identification and compilation of existing information are essential early steps in the process. The Alameda and Santa Clara programs benefited from these steps for several reasons, including that they provided a learning experience on the importance of the relationship of land-use information to water quality. Much pertinent information already existed, and many existing municipal activities were involved in the management of urban runoff and pollutant sources. This information was critical to the identification of monitoring, modeling, and mapping needs, and to the selection of appropriate control measures.

Neither of the programs chose to focus resources on detailed mapping efforts. Rather, available maps were used to compile information. Development of more detailed maps, specifically geographical information systems, was deferred to the implementation phase of the program when funding mechanisms would be in place and the cost could be better justified.

### *Monitoring and Modeling*

Both the Santa Clara and Alameda programs conducted comprehensive monitoring and modeling programs (1, 2). The objectives of these programs were to characterize existing water quality conditions within storm drains and urban creeks and to estimate urban runoff pollutant loading. The programs included hydrologic monitoring, wet and dry weather water quality monitoring, sediment monitoring, and toxicity monitoring using acute and chronic bioassays. Data were compiled and used to calibrate and verify the Storm Water Management Model for estimating pollutant loads. The load estimates were also used to compare the relative contributions of treated wastewater and urban runoff discharges to the bay.

Results of both monitoring programs were similar. Heavy metal concentrations in receiving waters increased during wet weather. The metals primarily detected were cadmium, copper, lead, nickel, and zinc. Pesticides and petroleum hydrocarbons were prevalent in sediments. Metal concentrations were distinctly different for discharges from open space, commercial/residential, and industrial areas. It was also determined that annual urban runoff pollutant loads were equal to or greater than treated wastewater discharges, depending on the amount of precipitation.

Each of the monitoring and modeling programs cost from $1 to $2 million. Much valuable information was gained, and there were strong driving forces for obtaining the pollutant load information. Future programs may not have this level of available resources during the planning process, however. Municipalities must weigh the cost of obtaining new data to make more informed decisions with the risk associated with making assumptions in the selection and implementation of control measures in lieu of data acquisition. Newly developing programs in the San Francisco Bay Area are taking this latter approach, in part benefiting from the information developed by the Santa Clara and Alameda programs.

### *Selection of Control Measures*

The process of selecting appropriate urban runoff pollution control measures involves three steps: 1) compilation of candidate control measures, 2) consideration of the candidate measures based on screening criteria, and 3) selection of control measures (3). The key to the success of the process was establishing meaningful selection criteria. The selection criteria addressed pollutant control effectiveness, reliability, and sustainability; capital, operation, and maintenance costs; public and agency acceptability; consistency with regulatory requirements; and legal and environmental liability.

An inventory of candidate control measures was developed through a review of technical literature and other urban runoff control programs. In addition, technical and managerial personnel from other state, county, and city agencies were interviewed. This initial screening produced a list of 92 separate candidate control measures. Upon application of the established screening criteria, the list was reduced to 59 control measures. The final step involved consideration of the overall costs of implementing all the control measures, with priority given to pollution prevention and source control measures over structural or treatment based controls. This final step ultimately lead to the selection of 41 separate control measures for implementation.

The Alameda program had the advantage of following the Santa Clara program. Consequently, the Alameda program streamlined the process by capitalizing on the efforts and progress of the Santa Clara program. The Alameda program also factored in the requirements of the storm water NPDES regulations. As more programs are developed, we expect the selection process to become even more streamlined, particularly in areas of similar land use and climatic conditions such as the San Francisco Bay area.

### *Implementation Plan*

The final stage of the planning process is to develop a plan for implementation of control measures. The implementation plan should provide a clear framework of stated goals, tasks to achieve them, an evaluation process, and a mechanism for modification of the plan based on program successes and failures. The task forces of the Santa Clara and Alameda programs played a critical role in the development of their implementation plans. The multiagency involvement on the tasks forces allowed for a consensus-building process that resulted in establishing responsible agencies and institutional arrangements for implementation.

The Regional Board did not intend to require immediate implementation of all control measures. Through involvement with the respective task forces, high-priority, early-action measures were identified, and schedules for phased implementation of the remaining measures were established. For example, targeted early actions included a public information program and surveillance for illegal discharges. Improved operation and maintenance activities are being implemented under a phased schedule where the efficiency of various inlet cleaning procedures are being evaluated on a pilot scale first (4, 5).

Development of a comprehensive and effective implementation plan for an urban runoff control program is the most critical and difficult step in the planning process. The difficulties encountered are generally nontechnical in nature and involve legal, financial, and institutional limitations. The key to avoiding or overcoming such limitations is recognizing them early in the planning process and integrating their solution into the planning process. For example, the planning process work plan should include tasks to address legal authorities, funding mechanisms, and institutional arrangements, rather than waiting until a technical implementation plan is drafted. In essence, development of the implementation plan should commence with initiation of the planning process.

## Conclusions

Development of an effective urban runoff control program requires a well-defined planning strategy. The experiences of the Regional Board and the Santa Clara and Alameda programs provide insight on how to efficiently proceed through the planning process. Understanding the benefits of each step of the planning process enables a municipality to focus limited resources on the more critical factors affecting development of an implementation plan. These factors include a multiagency task force; clear goals and a work plan for the planning process; compilation of all available information, with a strong emphasis on review of other programs; strategic focus of monitoring, modeling, and mapping resources; criteria for selection of control measures; and the foresight to commence development of the implementation plan at the beginning of the planning process. Lessons learned to date are now being used by other municipalities in the San Francisco Bay area, leading to timely and cost-effective development of urban runoff management programs.

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# *Whole Basin Planning: Practical Lessons Learned From North Carolina, Delaware, and Washington*

**Michael L. Bowman**
**Tetra Tech, Inc., Owings Mills, Maryland**

**Clayton S. Creager**
**The Cadmus Group, Inc., Petaluma, California**

## Abstract

Governments at all levels are broadening their view of water quality protection and are developing and implementing innovative strategies to achieve greater water resources protection. Many of these efforts center on "whole basin planning," which encourages active coordination across the full range of resource management programs to maximize the efficiency of program planning and administration, data collection and analysis, pollution prevention and control implementation, habitat protection and restoration, permitting, and enforcement.

Basin planning consists of two phases. The first develops the design of the state- or multistate-specific framework under which basin planning will be performed. The second phase implements the basin planning process. North Carolina, Delaware, and Washington have each employed a consensus-building, workshop-based process to develop planning frameworks. Delaware and Washington are currently in the framework design phase. North Carolina implemented basinwide planning in 1991. Preliminary results are encouraging, with improvements to the state's monitoring program, data management, analysis and assessment, and water quality program administrative functions being demonstrated.

Several aspects of the framework development process as employed in these three states stand out as practical suggestions for other states and federal and local agencies considering basin planning:

- Clearly define the state-specific objectives to be achieved.
- Encourage stakeholder involvement at the agency staff level.
- Allow time for discussion of ideas and iterations during framework development.
- Build in flexibility to the process development and basin planning processes.
- Define issues to address in order to translate objectives for basin planning into specific tasks.
- Implementing basin planning, the states found, does not necessarily lead to disruption of existing programs.

## What Is Whole Basin Planning?

There is a growing awareness in the United States that point source water pollution control programs have been successful, but that nonpoint sources, groundwater contamination (1, 2), and habitat degradation (3) continue to diminish the quality of the nation's water supply. Point source chemical controls, while largely effective, have not led to the achievement, maintenance, nor protection of the three supporting components of clean water provided in Section 101(a) of the Clean Water Act (CWA): chemical, physical, and biological integrity. Nonchemical stressors resulting from nonpoint source pollution (e.g., "clean sediment," increased stream temperature, highly modified flow regimes) can lead to direct and indirect impacts on physical and biological integrity. A broad perspective on water resources management is required to reduce and eliminate such stresses. Government agencies at federal, state, and local levels are widening their views of water quality protection and are developing and implementing innovative strategies to achieve greater water resources protection. Many of these efforts center on the concept of a "whole basin planning" (WBP) approach, which realigns water pollution control programs to operate in a more comprehensive and coordinated fashion.

The underpinnings of basin planning can be found in federal legislation, notably numerous sections of the CWA (Table 1). Section 303(e) explicitly requires each

**Table 1. Sections of the CWA That Support Basin Planning (Adapted From Craeger et al. [4])**

| Section | Applicable Content |
|---|---|
| 201(c) | To the extent practicable, waste treatment management shall be on an areawide basis. |
| 208 | Several clauses of this section call for areawide planning, reporting, and pollutant control. |
| 303(d) | Subsection 1A. Each state shall identify waters within its boundaries which are water quality limited. The state shall establish a priority ranking for such waters. |
| 303(d) | Subsection 1C. States shall establish TMDLs for the identified water quality limited waters. |
| 303(e) | Establishes a continuing planning process that includes effluent limits and compliance schedules, applicable areawide waste management plans (§208) and basin plans (§209), TMDLs per §303(d), revision procedures, authority for intergovernmental cooperation, implementation including compliance schedules, residual waste disposal controls, and a prioritized inventory and ranking of waste treatment construction needs. |
| 319(a) | Nonpoint source management program, state assessment reports. |
| 319(b) | Nonpoint source management program, state management plans. |
| 319(b) | Section 4. States shall develop and implement management programs on a watershed basis. |
| 320 | Comprehensive management plans to be developed over large geographic area for estuaries in National Estuary Program. |

state to develop an areawide planning process for all navigable waters in the state to address a broad range of water quality issues. Sections 303(d) and 319 implicitly require or support basin planning. Section 303(d) requires states to define total maximum daily loads (TMDLs), as well as associated wasteload allocations for point sources and load allocations for nonpoint sources, to ensure the attainment of water quality standards within all surface waters. Section 319 requires watershed-based nonpoint source management programs. Section 320 establishes the National Estuary Program and requires the development of management plans for estuaries included in the program. The estuarine zone is broadly defined as extending to the upstream limit of historic anadromous fish migration or head of tide. Thus, the management plans must be prepared for broad geographic areas. In addition to the CWA, the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) included Section 6217, which requires coastal states with approved coastal management programs to develop Coastal Nonpoint Source Control Programs. During a review of state coastal zone boundaries required by Section 6217, National Oceanic and Atmospheric Administration will use U.S. Geological Survey (USGS) mapping units as the basis for examining state delineations of coastal watersheds (5). Section 6217 requirements provide implicit support for whole basin planning.

In a recent paper discussing integrated basin management, Downs et al. (6) identify five main facets that should be included when addressing the physical and biological attributes of river basins (Figure 1). Explicit incorporation of water, channels, land, ecology, and human activities management into the planning, design and implementation phases of aquatic resources management increases the likelihood that cumulative, incremental losses to resource quality and quantity will be identified and addressed. Whole basin planning encourages active coordination across the full range of resource management programs to maximize efficiency of program planning, data collection and analysis, pollution prevention and control implementation, habitat protection and restoration, permitting, and enforcement. Mitchell (7) recommends a two-stage strategy to achieve truly coordinated management of resources in river basins. The first, conceptual stage is an identification of the widest possible range of issues and variables. The second, operational stage involves an integrated, focused approach that concentrates on the issues identified as most significant.

The U.S. Environmental Protection Agency (EPA) has recognized the value of taking a wider view of water quality protection. Through the Office of Water, EPA encourages states to implement watershed protection and basin planning and has formulated three main principles to guide its support for state efforts in this area (8):

- Risk-based geographic targeting
- Stakeholder involvement
- Integrated solutions

### *Risk-Based Geographic Targeting*

"Risk" in the context of whole basin planning refers to indication of impairment to human health, ecological

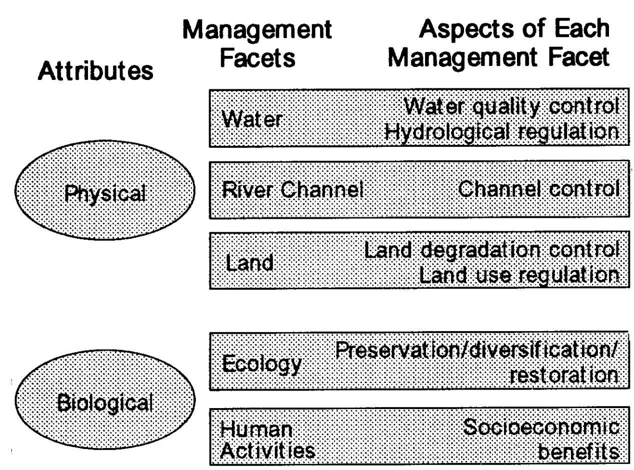


**Figure 1. Facets of river basin management to include in basin planning (adapted from Downs et al. [6]).**

resources, designated uses of the waterbodies, or a combination of these, resulting from manmade pollution and natural processes, based on a review of environmental data. A probabilistic approach, as is used in ecological risk assessment (9), has not been applied in basin planning. Phillips (10), however, argues for a probabilistic approach to targeting nonpoint source pollution control in a watershed context. Basin planning establishes a framework within which a more probabilistic risk assessment can be performed.

Problems that may pose risks in a watershed include:

- Industrial wastewater discharges.
- Municipal wastewater, stormwater, or combined sewer overflows.
- Waste dumping and injection.
- Nonpoint source runoff or seepage.
- Accidental toxics releases.
- Atmospheric deposition.
- Habitat alteration, including wetlands loss.
- Flow alterations.

Specific stressors within watersheds are targeted based on their potential to produce impairment to human health, ecological resources, or designated uses. Under a whole basin planning framework, the highest risk stressors within watersheds are identified using, for example, water quality and biological monitoring data, land use information, information on location of critical resources, and tools such as water quality models and geographic information systems (GIS). The stressors with the greatest potential to yield impairments are targeted for integrated assessment and corrective action involving cooperative efforts between multiple jurisdictions and interest groups. The targeting process may range from qualitative ranking to computerized techniques that incorporate various numeric criteria and weighting factors (11). Difficult management problems may not be completely addressed over the course of one basin planning cycle (5 years is being used in North Carolina). This can be used to advantage, however, by breaking the identified problems into components that can be solved, or for which measurable progress toward a solution can be made during a cycle.

The basin planning process itself can be broken into phases with near- and long-term goals. For example, near-term goals could include coordinating the permitting and monitoring schedules by basin, promoting public participation in basin planning, and expanding and improving wasteload allocation analyses and evaluation of nonpoint sources. Long-term goals could include optimizing the distribution of assimilative capacity within basins and developing and implementing basinwide management strategies.

### *Stakeholder Involvement*

All parties with a stake in the specific local situation should participate in problem analysis and creation of solutions. The involvement of potentially affected parties ("stakeholders") during the development of basin plans is crucial to the success of those plans. The manner in which stakeholders are involved may vary from state to state, but a key activity for them, regardless of location, is to reach consensus on goals and approaches for correcting a watershed's problems, specific actions necessary to achieve those goals, and processes for coordinating implementation activities and evaluating the efficacy of problem solutions. The potential pool of stakeholders can be very broad and should be tailored to individual basins. Potential basin plan participants include members of:

- State environmental, public health, agricultural, and natural resources agencies.
- Local/regional boards, commissions, and agencies.
- EPA water and other programs.
- Other federal agencies (e.g., U.S. Department of Agriculture—Soil Conservation Service, U.S. Department of the Interior, U.S. Army Corps of Engineers).
- Indian tribes.
- The public.
- Private wildlife and conservation organizations.
- Industry.
- The academic community.
- The farming community.

### *Integrated Solutions*

The basin approach provides a framework to design the optimal mix of water quality management strategies by integrating and coordinating across program and agency boundaries. Integrated solutions implemented by basin management teams use limited resources to address the most significant water quality problems without losing sight of and planning for other factors contributing to the degradation of the resource. Integration through the basin approach provides a means to achieve the short- and long-term goals for the basin by allowing the application of resources both in a timely and geographically targeted manner. Integrated solutions are possible because of a framework that encourages an interdisciplinary and interagency team to develop the most appropriate plan rather than impose predetermined solutions.

## Whole Basin Planning in Three States

Before basin planning (the second, operational stage in Mitchell's construct [7]) per se is implemented, it must be preceded by a process to design the framework within which it will operate (Mitchell's first, conceptual stage [7]). This design process will be specific to each state that implements whole basin planning due to differences in target resources (e.g., a large number of rivers and streams versus lakes), the objectives of implementing basin plans (e.g., a water quality permitting focus versus an aquatic resources management focus), and differing organizational structure and implementation constraints. We draw on experiences in North Carolina, Delaware, and Washington during the framework design stage of basin planning and identify several practical lessons that can be applied by other states, EPA regions, or other government units.

### *North Carolina*

#### The Framework

North Carolina Division of Environmental Management (NCDEM) Water Quality Section considered an National Pollutant Discharge Elimination System (NPDES) basin permitting strategy as early as 1989. However, due to resource limitations, NCDEM was unable to develop a framework document describing the strategy to submit to the North Carolina Environmental Management Commission for approval. NCDEM submitted a request for funding to the EPA Office of Policy, Planning and Evaluation, Water Policy Branch, for a facilitator to assist with the development of a basin approach for North Carolina. This consensus-building process was initiated in 1990.

#### The Process

The first step in the process involved a series of individual interviews with several members of the NCDEM Water Quality Section staff, including all branch chiefs. The benefits of expanding the focus from solely a NPDES permitting strategy to more comprehensive involvement of the water quality program soon became apparent. It was also clear that there was broad-based support for the basin approach but that individual views of that approach varied in several critical areas. The goal of the consensus process was to successfully synthesize those individual views.

The next step involved a series of small group meetings to begin outlining a framework for the basin approach. The results of these group meetings formed the basis for a "straw outline" compiled by the facilitator. The straw outline was used to provide structure for a "development" workshop attended by a large portion of the Water Quality Section staff. The purpose of the workshop was to finalize the outline and identify consensus positions. Workshop results were used to produce a draft internal document describing the North Carolina Whole Basin Water Quality Management Framework.

The draft framework document was distributed within the Water Quality Section for review and comment. The revised document was circulated to a broader audience, including other state and federal agencies and selected academics. The draft framework document was presented at an implementation workshop, which included broader agency and public participation than previous meetings. The document was revised once again based on comments received at the implementation workshop and submitted to the North Carolina Environment Management Commission (EMC) for approval. The EMC approved the basin approach in 1991.

The framework document has been revised twice since its approval by the EMC. These changes reflect needed refinements recognized during the implementation and development of specific basin plans. These revisions have expanded the focus of basin plans and incorporate broader elements of the water resources program in North Carolina to ensure that the state's basin planning objectives are being appropriately addressed.

The final consensus basin approach established a rotating basin schedule for NPDES permitting, monitoring, and nonpoint source program implementation. These activities are performed for each basin on a 5-year cycle, with several basins moving through the planning cycle together. A general sequence of tasks over the 5-year planning cycle is illustrated in Figure 2. North Carolina basin plans are viewed as reports to the public, policymakers, and the regulated community. Revisions to the framework are addressing an insufficient public outreach program for the development of specific basin plans. Basin plans report on the current status of surface waters in the basin, identify major water quality concerns and issues, summarize projected trends in development and water quality, identify long-range management goals for the basin, present recommended management options, and discuss implementation plans (12). The plan also presents potential changes in

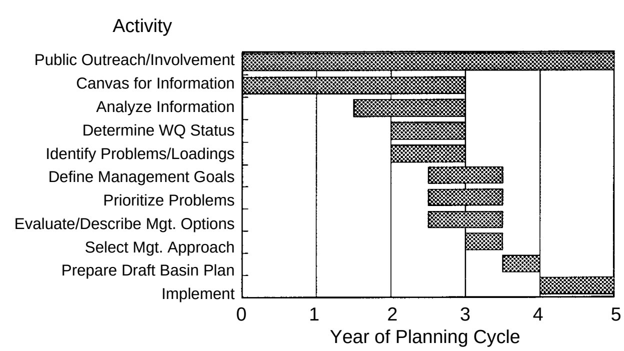


**Figure 2. General sequence of planning tasks.**

discharger waste limits and recommendations for reductions in nonpoint source loadings. North Carolina Basinwide Water Quality Management Plans do not, however, currently target specific physical habitat restoration issues or projects.

### Barriers to Implementation

A major impediment to the development and implementation of the North Carolina basinwide approach has also been the greatest source of strength: the CWA. The strength comes from the merger of traditionally regulatory programs, having strong legal precedence for enforcement, with voluntary compliance programs, which have a strong public involvement component. Each approach has enhanced the application of the other.

The barriers result from the manner in which the CWA has been implemented, using a programmatic approach with specific grant and entitlement programs. This has led to a lack of coordination and integration in addressing water quality issues that require comprehensive strategies. The program funding requirements reduce the flexibility of the state to commit funds to targeted water quality issues.

### Next Steps

A useful reform of the grants process would give states with defined basin frameworks authority to establish water quality priorities within basins. This approach would also reduce redundant application and reporting requirements that are fulfilled with the basin plans. Flexibility in this regard would enhance the North Carolina approach. EPA is currently using a trial block grant funding program with North Carolina.

## *Delaware*

### The Framework

The Delaware Department of Natural Resources and Environmental Control (DNREC) identified a need to focus existing water resources programs on priority watersheds. Basin planning will provide DNREC with the ability to assess pollution, living resources, and habitat problems, and manage Delaware's resources in a comprehensive manner (13). The department's perspective on basin planning, explicitly incorporating living resources and habitat degradation, from the outset of the process is significant from several standpoints. By including a wide range of basin management facets (Figure 1), DNREC will be more likely to proactively identify potential cost savings (e.g., combining aspects of current water quality and fisheries monitoring activities), watershed stressors with multiple impacts (e.g., loss of vegetated riparian buffer zones, which increases nonpoint source delivery to waterbodies and degrades aquatic and terrestrial habitat), and solutions with benefits to multiple resource categories (e.g., riparian zone revegetation, which reduces nonpoint source loadings and improves habitat). It is less likely that DNREC will need to "retrofit" the basin planning process at a later stage.

### The Process

DNREC's framework design process began with a series of interviews of department staff by a facilitator to gain a better understanding of their goals for basin planning in Delaware. Following completion of these interviews in late summer 1992, a workshop was held for DNREC staff in September 1992 to provide detailed background information on whole basin planning and to begin to identify existing roles and responsibilities of the various functional units within the department. The workshop provided an opportunity for department staff to identify perceived needs for basin planning in Delaware and to begin an initial formulation of goals and objectives (14).

A second workshop was held in January 1993 with DNREC staff and representatives from other state, local, and federal agencies. The goal of this session was to establish commitment and direction for basin planning in the state. The 3 months between the first and second workshops proved to be a very fertile incubation period for agency staff to consider the design of a planning approach. Key outcomes of the discussions were:

- Identification of a strategy of sequential involvement of a larger group of participants as the framework planning effort proceeds.
- Firm commitment by agency staff to build the planning process from the bottom up, together with the stakeholders who will actually implement it, rather than imposing the plan without their input.
- A clear statement that an expanded definition of "clean water" (i.e., inclusive of biological resources, physical habitat, and watershed linkages) would ensure that Delaware's basin approach is consistent with the goals and objectives of programs and agencies other than DNREC water programs. Maintaining the focus on "clean water" will allow the regulatory components of the basin approach to remain firmly grounded in legal and policy precedents provided by the CWA.
- Detailed discussion of whether to 1) proceed with immediate implementation of WBP in all basins at once, or 2) proceed incrementally, implementing the strategy in a single basin and then assessing the results and modifying the framework as appropriate.
- Tentative delineation of basin management units that combine groups of Delaware's 35 watersheds (Figure 3).

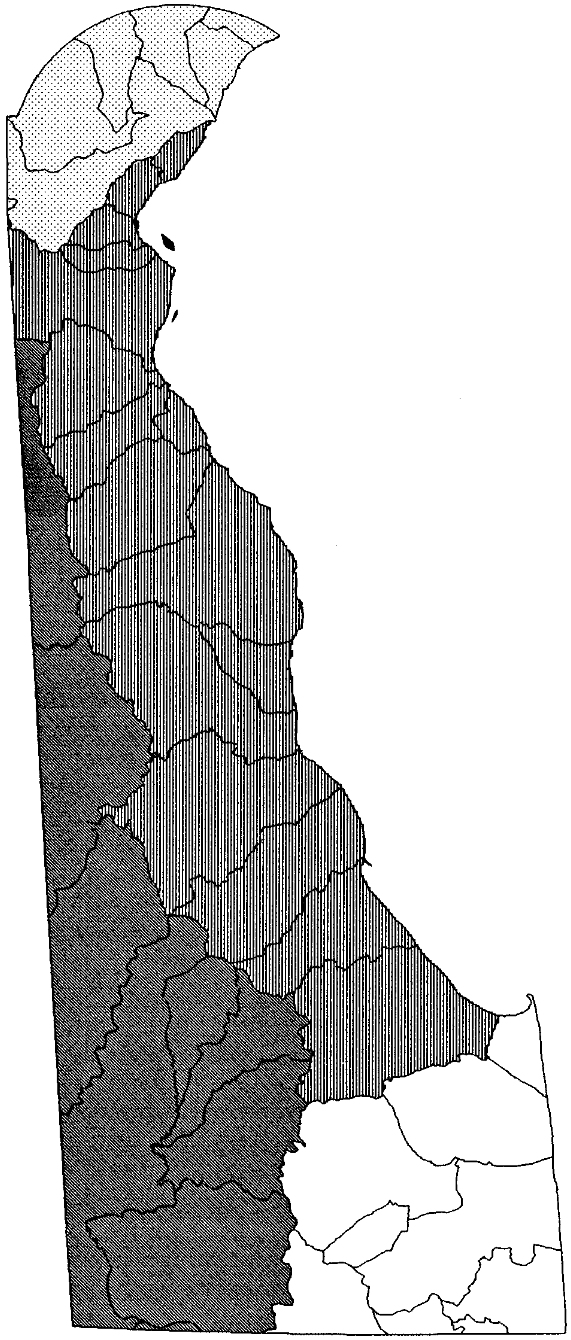

**Figure 3. Tentative delineation of basin management units in Delaware.**

Workshop participants identified a wide range of issues to address during the formulation of the basin planning framework. Review groups were established to explore these issues in greater detail and prepare specific components of a planning framework document. Topical areas being examined by these groups are:

- Implementation, coordination, and institutional barriers
- Management units, data management, and monitoring
- Public outreach and education

### Next Steps

The review groups will be the focus of planning activities for several months. Following completion of their deliberations, a framework design workshop will be convened to review the components of the planning process proposed by the groups, to make appropriate modifications, and to establish a draft basin planning framework for subsequent review by stakeholders.

## *Washington*

### The Framework

The Washington State Department of Ecology (DOE) Water Quality Program (WQP), Environmental Investigations and Laboratory Services (EILS), and Central Programs are currently developing the water quality component of a broader DOE basin approach to natural resource management. The process is the culmination of a long-term planning program that satisfies a state-sponsored Efficiency Commission requirement and also fulfills the requirements of a Memorandum of Understanding between EPA Region 10 and DOE. The development of the basinwide water quality management program framework document is not yet final. Therefore, the summary description offered here is subject to change. The development of the basinwide approach in Washington was also assisted by an independent facilitator.

### The Process

The Washington basin approach for water quality management involves coordinating issuance of wastewater discharge permits and nonpoint source planning conducted by the WQP and Central Program's Industrial Section (to the extent practicable). It also involves water quality monitoring, intensive field investigations, and TMDL development conducted by DOE's Environmental Investigations and Laboratory Services Program. Other programs within DOE also have developed or are developing basin approaches for their areas of responsibility (e.g., Coastal Zone Management, wetlands). All of the basin approaches within DOE will be merged into one resource management program at a later date.

Beginning in mid-1993, each of the WQP's four regions committed one basin per year to this geographically targeted, risk-based approach. The 64 Water Resource Inventory Areas (river basins) will be lumped into 20 basin management units. Each of the four regions will complete a basin water quality management plan each year. All of the basin management units across the state will be completed in a 5-year cycle. Each basin will be revisited every 5 years to restart the cycle of data collection, assessment, public outreach, planning, and implementation. Basin management teams are active in each basin management unit every year of the 5-year basin management cycle. Basins are simply staggered at different steps in the cycle. The Washington approach is viewed as a long-term commitment to a stable management structure that allows DOE to build on previous efforts.

Integration of the DOE program with local planning agencies is a key issue in Washington. DOE is placing a strong emphasis on stakeholder involvement through a public outreach program that is active at each step of the basin cycle. The roles and responsibilities of all of the participants on the basin planning team have not been finalized. DOE, however, is looking for a mechanism that promotes public and other agency involvement in all phases of the basin planning process. The exception would be when the regulatory activities of the basin planning team might directly affect a participant.

#### Next Steps

EPA flexibility is needed in numerous program components to facilitate DOE's transition to the basin approach, including:

- Using extended/expired permits to achieve synchronization of permits within basins, and because certain permits will receive a low priority ranking for risk of waterbody impairment.
- Allowing basin plans to fulfill various CWA reporting requirements (e.g., 305(b), 319).
- Using basin plans as both numeric and qualitative TMDLs.
- Administering staff/financial resources among various program components (e.g., number of inspections and audits).
- Focusing on the results of the water quality program rather than specific intermediate evaluation criteria.
- Recognizing that certain state discharge permits (e.g., ground water) may take precedence for management over certain NPDES permits.

EPA Region 10 and DOE are working together to resolve these issues to the extent possible within the current configuration of the CWA. The elimination of all institutional barriers between EPA regional offices and states may require some amendment of the CWA as part of its reauthorization.

Washington is continuing to resolve internal implementation barriers by establishing a cross-program work group to address issues that were identified at the development workshop. DOE also considers the basinwide water quality management framework document that is developed through this current consensus process the first phase of DOE's transition to basin resource management.

## How Is Whole Basin Planning Working?

### *North Carolina*

Although only one state is actually performing basin planning, the results so far are encouraging. EPA's Office of Water, Watershed Branch, sponsored a survey of the staff of the NCDEM Water Quality Section after basin planning was initiated there. Potential improvements and increased efficiency in North Carolina's water quality program were suggested in several areas.

#### Monitoring Program

Following implementation of basin planning, NCDEM was able to increase the number of water quality sampling stations and parameters measured. The respondents attributed this increase to the ability to optimize sampling strategies under a basin approach. The ambient water quality monitoring network has been maintained. NCDEM staff anticipate further improvements to the monitoring network as a result of increased coordination with other resource agencies and the larger role of the regulated community in the monitoring program.

#### Data Management, Analysis, and Assessment

During development of a basin planning approach, North Carolina identified major improvements to data management and analysis (both hardware and software) as being crucial to the success of the approach. Improved capabilities in this area are expected to reduce the Water Quality Section's reliance on North Carolina's central computing services and significantly reduce the Section's computing costs. Cost savings will be used to upgrade in-house hardware and software, which will in turn allow ready access to monitoring and geographic data needed to support basin planning.

Of particular note to municipalities is the ability to fund a staff position with the Water Quality Section to assist in the development of basin plans from the perspective of fulfilling municipal stormwater planning and control requirements. North Carolina cities will benefit from this arrangement by being able to reduce or eliminate redundant monitoring and modeling.

Significant improvements have been made in assessing water quality issues. The development of a framework for basin planning included integration of analysis time requirements with monitoring schedules, thus monitoring now more directly supports water quality modeling. By shifting to a basin focus, modeling is performed for a greater length of stream segments in the state. This expansion allows consideration of more innovative solutions to water resources management issues, such as pollutant trading, and enhances the state's ability to prepare TMDLs.

### Administration

North Carolina's basin approach was designed to avoid agency reorganization. The approach has led to changes in roles and responsibilities for staff and branches within NCDEM. Staff resources have been shifted to place a greater emphasis on data acquisition and assessment. Information flow and coordination of activities between branches has significantly increased. A basin coordinator position was created to ensure the timely flow of information throughout the preparation of basin plans. In addition to improved communication and coordination within the NCDEM, there is increased cooperation with other local, state, and federal agencies.

### Potential Benefits to the Regulated Community

Basin planning has not been in place long enough to have provided directly measurable benefits to the regulated community. However, the Water Quality Section identifies several anticipated benefits. Consolidation of dischargers into consortia along stream reaches will provide an economy of scale with respect to permit monitoring requirements. Dischargers in management units are expected to be able to combine permit monitoring activities and cooperate in the preparation of assessments. NCDEM also expects permits to be more stable because of the expanded spatial and temporal scope of assessments performed during the basin planning cycle. Basin planning allows more comprehensive assessment of existing and proposed pollution sources, and is more effective in accounting for future impacts. Thus, permit conditions would need to be updated less frequently, potentially reducing costs to both NCDEM and permittees. Increased accuracy in the assessment of a basin's assimilative capacity will allow better identification of the level and types of controls necessary to achieve and maintain desired aquatic resources quality. Basin planning will help lead to the selection of an optimal set of pollution control methods, potentially reducing costs.

## *Neuse River Basinwide Plan*

North Carolina has implemented basinwide planning beginning with the Neuse River basin (Figure 4). Basinwide plans will be prepared for the remaining 16 basins in the state over the next 5 years and will be updated at 5-year intervals.

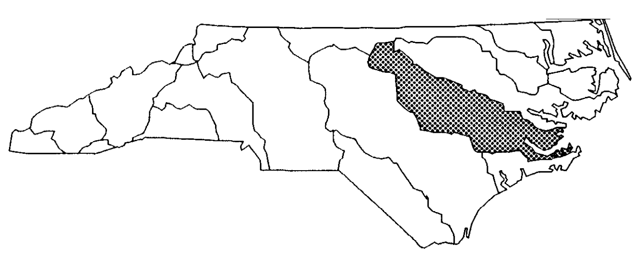

**Figure 4. North Carolina basins (Neuse River highlighted).**

North Carolina's basinwide planning process has as primary goals "to identify and restore full use of presently impaired waters, to identify and protect highly valued resource waters, and to manage problem pollutants throughout the basin so as to maintain full use of unimpaired waters while accommodating population increases and economic growth" (12). NCDEM identified near- and long-term objectives for its basinwide planning process that apply to the preparation of basin plans (illustrated conceptually in figure 2). Near-term objectives are defined as those fully or partially achievable during the initial 5-year planning cycle. They include implementing management strategies to significantly reduce point and nonpoint source pollution and making measurable improvements toward addressing major issues identified in each of the basin plans. Longer-term objectives include refining the recommended basinwide management strategies during subsequent planning cycles based on the results of monitoring and implementation activities from the initial round of planning (12).

The Neuse River basinwide plan is a comprehensive document that can serve as a model for other states considering basin planning. An outline of the contents of the document is provided in Table 2.

## Practical Lessons From Framework Development

As noted earlier, several states are in the process of developing a whole basin planning framework, or have completed the framework and implemented basin planning. Several aspects of the framework development process in these states stand out as practical suggestions for other state, federal, and local agencies that may be considering basin planning:

- *Clearly define the specific objectives to be achieved:* This will determine the scope of the programs to be involved. The objectives are a positive statement of the issues to be addressed and resolved through the basin approach. This step eliminates uncertainty regarding the focus of the consensus process. Basin planning entails a considerable shift in thinking and practice regarding the manner in which resources will be managed. It moves agencies (and other stakeholders) from programmatic-based management to resource-based management. This shift does not necessarily require agency reorganization, but it does require emphasis on and sustained commitment to extensive communication and information sharing across programmatic lines.
- *Encourage stakeholder involvement at agency staff level:* The basin approach allows redefinition of functional relationships without formal reorganization.

**Table 2. Neuse River Basinwide Plan**

| | |
|---|---|
| Introduction | Purpose of the Neuse Basin Management Plan<br>Guide to Use of Document<br>Introduction to the Basinwide Management Approach<br>Basinwide Responsibilities Within NCDEM Water Quality Section |
| General Basin Description | Physical and Geographic Features<br>Land Use, Population, and Growth Trends<br>Major Surface Water Uses and Classifications |
| Sources and Causes of Water Pollution in the Neuse Basin | Introduction<br>Defining Causes of Pollution<br>Point Sources of Pollution<br>Nonpoint Sources of Pollution |
| Water Quality Status in the Neuse Basin | Sources and Types of Water Quality and Biological Data<br>Narrative Water Quality Subbasin Summaries<br>Neuse River Mainstem<br>Methods for Determining Water Quality "Use Support" Ratings |
| Existing Point and Nonpoint Source Control Programs | Introduction<br>Integrating Point and Nonpoint Source Pollution Control Strategies<br>Point Source Pollution Control Through North Carolina's NPDES Permitting Program<br>Nonpoint Source Control Programs |
| Basinwide Goals, Major Water Quality Concerns and Recommended Management Strategies for the Neuse Basin | Major Water Quality Concerns and Priority Issues<br>Recommended Management Strategies for Oxygen Demanding Wastes<br>Management Strategies for Nutrients<br>Toxics |
| Basinwide Plan Summary and Future Initiatives | Overview of Neuse Basinwide Goals and Objectives<br>Neuse NPDES Permitting and TMDL Strategies<br>Nonpoint Source Control Strategies and Priorities<br>Future Modeling Priorities<br>Future Monitoring Priorities<br>Future Programmatic Initiatives |

The more broadly based the transition effort, the less confusion in the implementation of the approach. The basin approach also "flattens" organizations by shifting more decision-making responsibility to basin teams. Therefore, staff involvement is critical to development of the basin approach. Staff made many valuable contributions to the process and more eagerly embraced the approach in those states where staff participation was encouraged.

- *Allow time for adequate, thorough discussion of ideas and iterations during the development of the process framework*: Development of a basin planning process is complex and, as noted above, requires a shift in agency thinking and practice. Although no hard-and-fast guidance can be given on the specific lengths of time that are needed for each of the phases of the framework development process, experience in three states suggests that a minimum of 12 to 18 months should be allowed. By allowing adequate time for agency staff to thoroughly explore potential requirements of basin planning and issues identified during the preparation of a planning framework, a much stronger process will result.

- *Build in flexibility to the development process as well as the whole basin planning process itself:* The three states discussed in this paper have all employed a consensus-building, workshop-based process to develop planning frameworks. On occasion, workshops have been rescheduled at the last minute when it became clear that adequate numbers of participants would not be available because of scheduling conflicts. Also, workshop agendas underwent substantial modification at the session when it became clear that participants needed more in-depth discussion of basin planning concepts or particular issues they had identified. These conditions should not be viewed in a negative light—they are almost certain to occur in a consensus process, and the ability to respond with flexibility is essential to maintaining the momentum generated earlier in the process.

- *Define issues to address in order to translate objectives for basin planning into specific tasks:* Identification of certain core issues is essential for translating state-specific basin planning objectives to specific tasks that will be accomplished in the development of basin plans. Some issues that have been commonly identified across several states thus far include cross-program coordination, roles and responsibilities in the existing resource management scheme versus modifications necessary to implement basin planning, policy and regulatory implications at the state and federal level, and human and capital resources needs.

As noted above, basin planning emphasizes cross-program communication and coordination. Institutional and regulatory constraints, which vary from state to state, may lead to some disruption of existing programs during the transition period. Such disruptions can be minimized by carefully considering the steps needed to move from programmatic to resource-based management during the framework development process.

## Acknowledgments

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# Application of Urban Targeting and Prioritization Methodology to Butterfield Creek, Cook and Will Counties, Illinois

**Dennis Dreher and Thomas Price**
**Northeastern Illinois Planning Commission,**
**Chicago, Illinois**

## Abstract

This paper describes the applicability of a methodology, developed by a consultant for the U.S. Environmental Protection Agency, to select, target, and prioritize best management practices (BMPs) in an urban watershed. The methodology was demonstrated in the Butterfield Creek watershed in South Cook County, Illinois. This watershed was selected because there are no major point sources of discharge to the creek, thus the impacts due to nonpoint sources alone could be addressed.

The methodology considered watershed land use, contributing nonpoint sources, and stream use attainment to identify priority areas for BMPs and then to prioritize those areas. The primary focus of the methodology, as originally developed, was to reduce problematic pollutant loads via appropriate BMPs. One shortcoming of the procedure was that it was limited to pollutant loads and, therefore, was not readily able to address other factors, such as the physical habitat impairments that affect many urban streams. Several enhancements were added to the methodology to address this situation. Also, the watershed configuration made interpretation of the prioritization results less straightforward.

The targeting methodology was enhanced in this application by presenting stormwater runoff rate as an additional targeted factor. Similarly, BMP selection and quantification were enhanced by representing the control of stormwater runoff rate by detention retrofitting.

## Introduction

### Purpose

The purpose of this paper is to report on a demonstration of a methodology developed by Woodward-Clyde Consultants for the U.S. Environmental Protection Agency (EPA) to select, target, and prioritize best management practices (BMPs) in an urban watershed (1). This methodology considers watershed land use, contributing nonpoint sources, and stream use attainment to identify priority areas for BMPs. The primary focus of the methodology, as developed, is to reduce problematic pollutant loads via appropriate BMPs. The methodology does not, however, address other constraints to stream use attainment, such as hydrologic destabilization and loss of physical habitat.

Butterfield Creek was selected for this demonstration for several reasons. First, watershed impacts are primarily due to nonpoint sources; there are no major point sources of discharge to the creek. Second, a preliminary nonpoint source management plan was being developed under a Section 319 grant, and this methodology could be used to assist in development of that plan. As a result, this paper presents analyses and results from both the preliminary nonpoint source plan (2) and the targeting methodology application (3). These two projects were originally documented separately, as referenced.

Assessment of Butterfield Creek problems has benefitted from the presence of a group known as the Butterfield Creek Steering Committee. The committee includes representatives from seven local governments in the watershed, and its mission is to address comprehensive stormwater management issues. While the primary focus of the committee has been the reduction of existing flooding problems, it also has identified the protection and improvement of water quality as major objectives. While committee members are concerned about water quality, they are also concerned about the potential expense of retrofitting urban BMPs in already developed areas. Therefore, a goal is to target BMPs to priority areas, where their effectiveness is maximized.

### Background

Butterfield Creek drains a 26-square-mile watershed in Cook and Will Counties in northeastern, suburban

Illinois. Its land use is largely residential and commercial in downstream areas. Much of the upstream watershed is presently undeveloped, although urbanization is anticipated. Existing water quality and stream use data indicate degraded conditions. There are no major permitted point source discharges to the stream, leading to the conclusion that nonpoint source impacts are the likely causative factors for the observed conditions.

### *Targeting and Prioritization Procedure*

The elements of the targeting and prioritization procedure are as follows:

- Characterization of the watershed, including:
  - Subwatershed identification
  - Land-use identification
  - Nonpoint source impacts
- Incorporation of additional relevant factors, based on watershed conditions, into the documented targeting procedure.
- Calculation of pollutant loads and completion of targeting table.
- Prioritization of drainage areas for nonpoint control.

## Characterization of Butterfield Creek

### *Subwatershed Identification*

Butterfield Creek is composed of three primary subwatersheds; the mainstem, the east branch, and the west branch. The two branches are parallel systems that are tributary to the mainstem. Approximately 25 percent of the watershed drains to the east branch, and approximately 36 percent of the watershed drains to the west branch. The remaining 39 percent of the watershed drains directly to the mainstem, which is entirely downstream of the two branches.

### *Land-Use Identification*

Land use in the Butterfield Creek watershed was interpreted from 1990 aerial photographs (1 in. equals 400 ft). This information was then digitized and entered into an ARC/INFO geographic information system. Subwatershed boundaries also were entered into the system, and land-use totals were cumulated for both the total watershed and the three distinct subwatersheds (west branch, east branch, and mainstem). This information is presented in Table 1.

About 55 percent of the watershed has been developed into the following urban land-use categories: industrial, commercial/institutional, residential, highway/arterial roadway, railroad, and urban park and golf course. The remainder, including woodland/wetland areas, agricultural land, and vacant land, remains undeveloped. Most of the undeveloped land lies in upstream parts of the watershed, particularly the west branch.

### *Stream Conditions*

Stream conditions were assessed based on review of existing aquatic life, water quality, and sediment quality data as described in the preliminary nonpoint source plan (2). Physical habitat data were collected during development of the preliminary nonpoint source management plan.

#### Aquatic Life, Water Quality, and Sediment Quality

The existing data indicated degraded fish community conditions throughout the watershed. As is typical with many urban streams, species diversity and number are quite low relative to less urbanized streams in Illinois. Water quality conditions were also generally degraded, particularly in the more urban reaches. Sediment quality data paralleled the water quality data, with more elevated levels recorded in urban reaches.

#### Physical Habitat

Physical habitat conditions in Butterfield Creek were assessed during field visits to the creek. Data were collected on stream condition reporting forms created for the nonpoint source management planning effort. Conditions such as degree of channelization, stream and riparian vegetation, substrate material, erosion and sedimentation, and observations of benthics and macroinvertebrates and fish species were recorded. The site visits indicated highly variable conditions. The west and east branches tended to be highly channelized as a result of agricultural and urban drainage activities. Mainstem reaches tended to be less altered but appeared to suffer from the effects of flow destabilization due to urban stormwater runoff. Channel erosion and widening was prevalent in many downstream reaches.

### *Assessment of Nonpoint Source Impacts*

Considering all available information from Butterfield Creek and comparing its characteristics to other streams in Illinois, the following conclusions were made regarding nonpoint source impairment in Butterfield Creek.

#### Stream Uses

Many potential stream uses identified by the Illinois Environmental Protection Agency (IEPA) are inherently constrained by the size and flow of Butterfield Creek. Uses that Butterfield Creek can be expected to support and that were evaluated are fish and aquatic wildlife (including warm water fishery), body contact recreation, and noncontact recreation. IEPA assessments indicate that present stream uses are moderately impaired.

**Table 1. Watershed Land Use (square miles)**

| Land Use Category | Subwatershed: West Branch | Subwatershed: East Branch | Subwatershed: Mainstem | Total Watershed: Square Miles | Total Watershed: Percent of Total |
|---|---|---|---|---|---|
| Industrial | 0.037 | 0.079 | 0.022 | 0.14 | 0.54 |
| Commercial/Institutional | 0.196 | 1.027 | 0.669 | 1.89 | 7.38 |
| Low-density residential | 1.342 | 1.369 | 4.035 | 6.75 | 26.33 |
| High-density residential | 0.230 | 0.188 | 1.655 | 2.07 | 8.09 |
| Vacant | 0.980 | 1.236 | 0.657 | 2.87 | 11.22 |
| Open land/urban park | 0.171 | 0.152 | 1.552 | 1.87 | 7.32 |
| Highway/arterial road | 0.541 | 0.265 | 0.296 | 1.10 | 4.30 |
| Agriculture | 3.954 | 1.816 | 0.233 | 6.00 | 23.43 |
| Woodland/wetland | 1.828 | 0.274 | 0.568 | 2.67 | 10.43 |
| Railroad | 0.019 | 0.082 | 0.143 | 0.24 | 0.95 |
| Watershed total | 9.30 | 6.49 | 9.83 | 25.62 | 100.00 |
| Watershed rank value | 3.63 | 2.53 | 3.84 | 10.00 | |

While Butterfield Creek is not presently used to a great degree for water-based recreation, it is a potentially valuable unit of the downstream Thorn Creek and Little Calumet River systems. Also, Butterfield Creek is a valuable indicator of the nonpoint source effects of urbanization on receiving stream quality in northeastern Illinois. Improvement of uses in the larger streams will require the successful restoration of streams such as Butterfield Creek.

### Stream Use Impacts

Based on existing data, the most readily identified impacts to uses in Butterfield Creek are related to degraded physical conditions. These conditions include degraded physical habitat, as evidenced by artificially modified or eroded channels, and impaired aesthetics, due in part to debris and trash. Low dissolved oxygen also appears to be a limiting constraint to improved aquatic life uses, particularly in the east branch and several reaches of the mainstem.

Several other water quality factors, including toxicity to aquatic life, turbidity, and siltation, were identified as contributing constraints to improved stream uses. Based on existing data from Butterfield Creek and other urban streams, however, whether these water quality factors by themselves limit the potential stream uses in much of Butterfield Creek is unclear.

### Causes of Stream Use Impacts

The primary causes of stream use impacts in Butterfield Creek include physical habitat alterations, flow destabilization, channel erosion, bacterial contamination, nutrient enrichment, and noxious aquatic plants/algae.

Other suspected causes of use impairment include heavy metals, pesticides, oil and grease, unknown toxicity, organic enrichment, and suspended solids. Again, relying on the existing database, determining the degree to which these latter causes adversely affect stream use attainment is difficult.

### Contributing Nonpoint Sources

The most prevalent nonpoint source responsible for use impairment in Butterfield Creek is urban runoff, which causes both physical and chemical degradation of the creek. Other significant nonpoint sources include streambank modifications, channelization, and removal of riparian vegetation.

Several other sources have been identified as contributing to stream use impairment, although their relative effects are much less certain. These include onsite wastewater systems, illicit sewer connections, golf course runoff, draining/filling of wetlands, construction site runoff, debris jams/beaver dams, carp/nuisance fish, and nonirrigated crop production.

Finally, potential point-source-related impacts were noted but could not be quantified. These included the treated wet-weather discharge from the former Homewood wastewater treatment plant, wastewater discharges from Ely's Mobile Home Park and Idlewild Country Club, and sanitary sewer overflows.

## Application of Urban Targeting Methodology

### *Overview of Procedure*

#### Objectives of Butterfield Creek Application

This section describes the application of the targeting methodology to Butterfield Creek. The major purpose of this effort is to assess the applicability of the methodology for nonpoint source watershed planning in northeastern Illinois streams.

#### Comparison of Butterfield Creek Application to Example Watershed

The assessment of nonpoint source impacts has led to some very important conclusions that drive the application of the targeting methodology for Butterfield Creek. Perhaps unlike many other urban watersheds, the nonpoint source assessment of Butterfield Creek did not identify pollutants delivered by urban runoff (e.g., heavy metals, toxic organics) as the primary cause of use impairment. Instead, physical disturbances, including stream channelization and flow destabilization, appear to be among the most significant causes of impairment. (Considering both physical and chemical effects, urban runoff is the most important nonpoint source requiring remediation in the mainstem of the creek.) This conclusion causes the BMP selection procedure to emphasize measures that control runoff rate as well as runoff quality. Because there is not a wide range of potential BMPs addressing this problem, BMP selection becomes more straightforward. As a result, this paper places more emphasis on the targeting aspect of the methodology.

Another difference between Butterfield Creek and the example watershed presented in the methodology report is that stream use attainment in Butterfield Creek does not vary dramatically among subwatersheds. All three subwatersheds of Butterfield Creek are significantly impaired, although the causes of impairment vary substantially among the subwatersheds.

Still another difference between Butterfield Creek and the example watershed is the orientation of the subwatersheds. In the example, there were three parallel stream segments. In Butterfield Creek, there are two parallel stream segments that are tributary to the third. Therefore, BMPs implemented in the two upstream watersheds affect both the local watershed and the downstream watershed. Similarly, adequately addressing problems in the downstream subwatershed without applying some BMPs in upstream areas may be impossible.

Further, the three watersheds differ significantly in the levels of potential use attainability. Both the west and east branches are headwater streams with low dry-weather flows. Mainstem flows are more substantial, and its larger channel dimensions allow greater potential for full stream use.

### *Computation of Pollutant Loadings*

The methodology report describes a procedure for estimating pollutant loadings by land-use category. The procedure involves the assignment of runoff coefficients and pollutant concentrations to watershed land uses.

#### Runoff Coefficients

The first step is to assign a dimensionless runoff coefficient to each land use. The runoff coefficient is a measure of the watershed response to rainfall events and is intended to be equivalent to the total storm runoff divided by the total rainfall volume for runoff-producing rain events. The runoff coefficient (Rv) is estimated from the percent imperviousness of individual land uses by the following equation (4):

$$Rv = 0.05 + (0.009 * \text{percent impervious}). \quad \text{(Eq.1)}$$

While this methodology is quite simplistic with respect to true watershed hydrologic response, it is an appropriate way to represent the relative runoff responses of different land uses to pollutant-generating rainfall/runoff events. As such, it represents only the short-term surface component of runoff and is not intended to represent the complete storm hydrograph.

#### Pollutant Concentrations

The methodology report also includes suggested pollutant concentrations for different land uses. These concentrations can be used in conjunction with the runoff coefficients to estimate differences in expected pollutant loads for different land uses. The methodology report makes it clear, however, that these concentrations are not intended to be used in the estimation of actual pollutant loads for the area. Also, the methodology report provides concentrations for just six land-use types. Four additional land uses were used to represent Butterfield Creek, and pollutant concentrations for these were derived from both local sources (5) and the methodology report.

Table 2 summarizes the runoff coefficient and pollutant concentration assumptions for the Butterfield Creek land uses. These estimates are used to reflect relative differences in runoff rates and pollutant loads and are not intended to estimate actual loads.

#### Pollutant Loadings

Pollutant loads from runoff and concentration are computed as follows:

**Table 2. Runoff Coefficients and Pollutant Concentrations by Land Use**

| Land-Use Category | Runoff Coefficient | Pollutant Concentrations (mg/L) TSS | O&G | TP | Copper |
|---|---|---|---|---|---|
| Industrial | 0.60 | 120 | 20 | 0.20 | 0.05 |
| Commercial/institutional | 0.80 | 80 | 20 | 0.20 | 0.05 |
| Low density residential | 0.20 | 100 | 5 | 0.60 | 0.03 |
| High density residential | 0.40 | 90 | 10 | 0.40 | 0.04 |
| Vacant | 0.10 | 60 | 0 | 0.20 | 0.01 |
| Open land/urban park | 0.10 | 50 | 0 | 0.60 | 0.01 |
| Highway/arterial road | 0.60 | 80 | 15 | 0.20 | 0.05 |
| Agriculture | 0.10 | 150 | 0 | 0.80 | 0.01 |
| Woodland/wetland | 0.05 | 50 | 0 | 0.20 | 0.01 |
| Railroad | 0.20 | 80 | 15 | 0.20 | 0.05 |

$$\text{Mass load (pounds)} = Rv * \text{area (acres)} * \text{concentration (mg/L)} * 0.227. \quad \text{(Eq. 2)}$$

This computation provides an estimate of the relative pollutant load per inch of runoff-producing rain.

### Runoff Rates

As previously indicated in the summary of nonpoint source impacts to the watershed, pollutant loadings in stormwater runoff do not appear to be the limiting cause of stream use attainment. The quantity or rate of runoff from urban land uses, however, does appear to be a limiting constraint to improved stream uses, especially for aquatic life. In particular, the expansion of impervious surfaces increases the rate and volume of runoff for storm events and reduces stream base flow. This altered hydrology destabilizes the receiving stream channel and adversely affects habitat. Another cause of physical habitat impairment is channel modification (e.g., channelization, armoring).

Although runoff rate was not used as a targeting factor during development of the methodology, it can be incorporated readily. The runoff coefficient provides a similar indicator of runoff "load" as the product of runoff coefficient and concentration provides for pollutant load.

## *Comparison of Relative Loads: Targeting*

### Watershed Pollutant Loads

Using the methodology described in the previous section, pollutant and runoff loads were estimated by land-use category for each subwatershed and the overall watershed. Tables 3 through 6 summarize pollutant loadings for total suspended solids (TSS), oil and grease (O&G), total phosphorus (TP), and copper, and Table 7 summarizes storm runoff.

**Total Suspended Solids.** Evaluation of Table 3 indicates that TSS loads vary by subwatershed, but not to a great degree. There is, however, a great deal of variability in loadings between land-use categories. This variability is based on differences in runoff coefficients and pollutant concentrations (summarized in Table 2).

Figure 1 presents TSS loadings in a different fashion. This map visually represents loading intensity. It suggests, for example, that TSS loads could be reduced significantly by targeting just those areas of the watershed that contribute at high rates (e.g., greater than 4,000 lb/mi$^2$). The nonpoint source assessment of Butterfield Creek identified TSS as a contributing cause of use impairment, particularly for aquatic life and recreational uses. While TSS does not appear to be as important as some other identified causes of use impairment (such as flow destabilization, physical habitat alteration, and channel erosion), it still should be addressed in the final watershed management plan. The targeting information presented in this section will be useful in determining a comprehensive control strategy.

**Oil and Grease**. O&G loadings as presented in Table 4 vary dramatically by both subwatershed and land use. The reason for this greater variability is the fact that oil and grease is assumed to originate completely from developed urban areas. Therefore, there is a relatively small loading in the mostly nonurbanized west branch subwatershed.

As with TSS, if O&G control was a high priority for stream use remediation, it would be relatively easy to identify areas for BMP targeting by using a map similar to Figure 1 for O&G. As indicated in the nonpoint source

**Table 3. Total Suspended Solids Loading (pounds per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| Land-Use Category | West Branch | East Branch | Mainstem | Pounds | Pounds/ Sq. Mile |
| Industrial | 389.0 | 827.1 | 233.8 | 1,450 | 10,357 |
| Commercial/institutional | 1,817.5 | 9,533.2 | 6,207.7 | 17,558 | 9,290 |
| Low-density residential | 3,892.9 | 3,970.6 | 11,700.0 | 19,564 | 2,898 |
| High-density residential | 1,200.3 | 983.5 | 8,641.3 | 10,825 | 5,229 |
| Vacant | 852.5 | 1,075.7 | 572.2 | 2,500 | 871 |
| Open land/urban park | 124.1 | 110.0 | 1,125.6 | 1,360 | 727 |
| Highway/arterial road | 3,765.5 | 1,846.2 | 2,061.7 | 7,673 | 6,976 |
| Agriculture | 8,601.9 | 3,951.9 | 505.8 | 13,060 | 2,177 |
| Woodland/wetland | 663.0 | 99.4 | 206.1 | 968 | 363 |
| Railroad | 44.1 | 189.3 | 332.4 | 566 | 2,357 |
| Watershed total | 2,1351 | 22,587 | 31,587 | 75,524 | 2,948 |
| Watershed rank value | 2.8 | 3.0 | 4.2 | 10.0 | |

**Table 4. Oil and Grease Loading (pounds per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| Land-Use Category | West Branch | East Branch | Mainstem | Pounds | Pounds/ Sq. Mile |
| Industrial | 64.9 | 138.1 | 39.0 | 242 | 1,739 |
| Commercial/institutional | 455.1 | 2,387.1 | 1,554.4 | 4,397 | 2,319 |
| Low-density residential | 195.0 | 198.8 | 586.3 | 980 | 145 |
| High-density residential | 133.6 | 109.4 | 961.7 | 1,205 | 580 |
| Vacant | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Open land/urban park | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Highway/arterial road | 707.2 | 346.7 | 387.2 | 1,441 | 1,304 |
| Agriculture | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Woodland/wetland | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Railroad | 8.3 | 35.5 | 62.4 | 106 | 435 |
| Watershed total | 1,564 | 3,216 | 3,591 | 8,371 | 327 |
| Watershed rank value | 1.9 | 3.8 | 4.3 | 10.0 | |

assessment, O&G is identified as a potential, but not major, contributor to use impairment.

**Total Phosphorus.** Total phosphorus loadings as presented in Table 5 vary the least among the land-use categories. This is explained by the fact that relatively high concentrations are assumed for low-density residential and agricultural land uses, and these concentrations counterbalance the relatively low runoff coefficients for these uses.

**Copper.** The last pollutant to be presented is copper. Copper loadings are presented in Table 6 and Figure 2. Relative differences in copper loadings are similar to those observed for O&G in that the heaviest loadings come exclusively from intensely developed urban land uses. Figure 2 makes clear that effective reduction of total copper loadings could be achieved by targeting a relatively small fraction of the total watershed for BMPs.

Available data, however, suggest that copper is not a major cause of stream use impairment in Butterfield Creek. While violations of the copper water quality standard occur with some frequency, acute toxicity to fish due to copper concentrations in stormwater does not appear to be problematic. Nonetheless, copper may be used as an effective surrogate for other urban runoff toxicants, particularly other heavy metals, which are believed to play a role in limiting aquatic life in the creek.

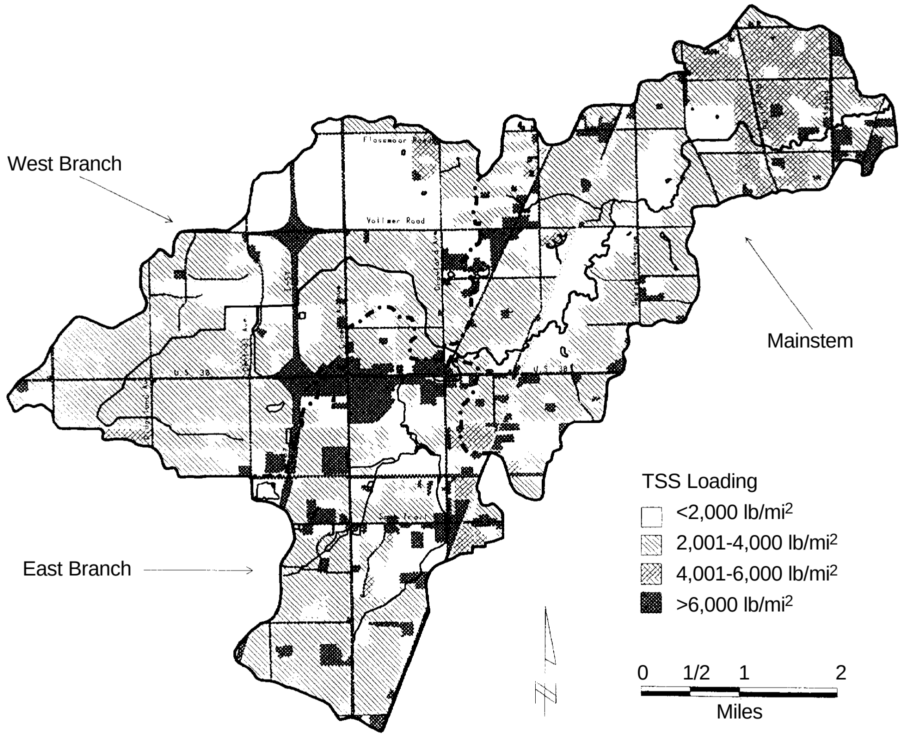


**Figure 1. TSS loading per inch of rain, Butterfield Creek.**

**Table 5. Total Phosphorus Loading (pounds per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| **Land-Use Category** | **West Branch** | **East Branch** | **Mainstem** | **Pounds** | **Pounds/ Sq. Mile** |
| Industrial | 0.648 | 1.379 | 0.390 | 2.4 | 17.4 |
| Commercial/institutional | 4.544 | 23.833 | 15.519 | 43.9 | 23.2 |
| Low-density residential | 23.358 | 23.824 | 70.238 | 117.4 | 17.4 |
| High-density residential | 5.335 | 4.371 | 38.406 | 48.1 | 23.2 |
| Vacant | 2.842 | 3.586 | 1.907 | 8.3 | 2.9 |
| Open land/urban park | 1.489 | 1.320 | 13.507 | 16.3 | 8.7 |
| Highway/arterial road | 9.414 | 4.615 | 5.154 | 19.2 | 17.4 |
| Agriculture | 45.877 | 21.077 | 2.698 | 69.7 | 11.6 |
| Woodland/wetland | 2.652 | 0.397 | 0.824 | 3.9 | 1.5 |
| Railroad | 0.110 | 0.473 | 0.831 | 1.4 | 5.8 |
| Watershed total | 96.3 | 84.9 | 149.5 | 330.6 | 12.9 |
| Watershed rank value | 2.9 | 2.6 | 4.5 | 10.0 | |

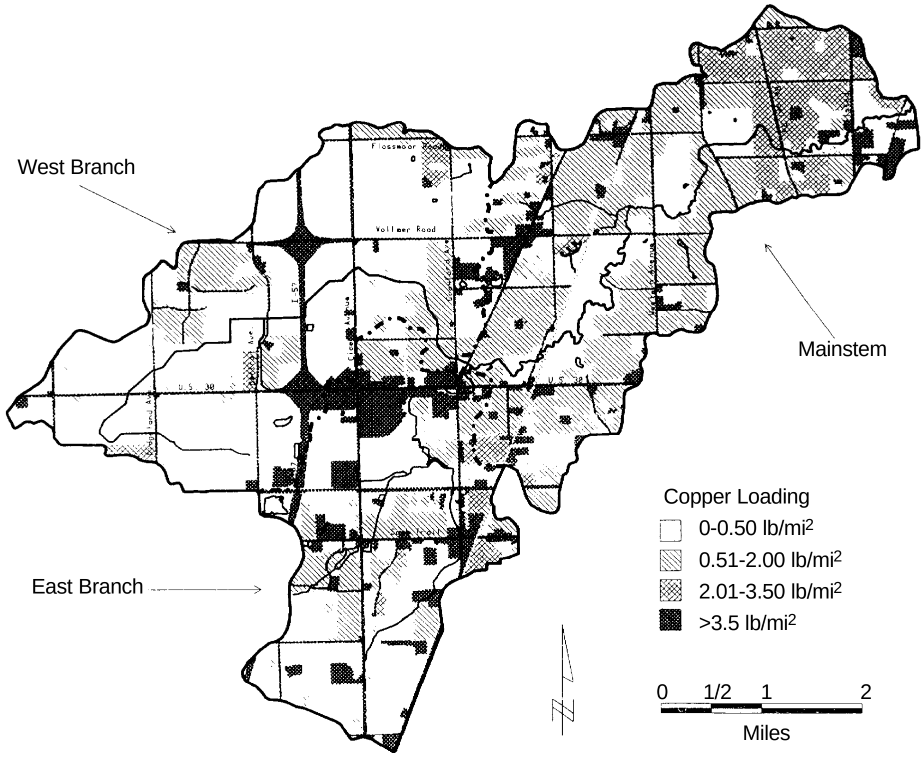


**Figure 2. Copper loading per inch of rain, Butterfield Creek.**

**Table 6. Copper Loading (pounds per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| **Land-Use Category** | **West Branch** | **East Branch** | **Mainstem** | **Pounds** | **Pounds/ Sq. Mile** |
| Industrial | 0.16 | 0.35 | 0.10 | 0.6 | 4.3 |
| Commercial/institutional | 1.14 | 5.97 | 3.89 | 11.0 | 5.8 |
| Low-density residential | 1.17 | 1.19 | 3.52 | 5.9 | 0.9 |
| High-density residential | 0.53 | 0.44 | 3.85 | 4.8 | 2.3 |
| Vacant | 0.14 | 0.18 | 0.10 | 0.4 | 0.1 |
| Open land/urban park | 0.03 | 0.02 | 0.23 | 0.3 | 0.1 |
| Highway/arterial road | 2.36 | 1.16 | 1.29 | 4.8 | 4.3 |
| Agriculture | 0.57 | 0.26 | 0.03 | 0.9 | 0.1 |
| Woodland/wetland | 0.13 | 0.02 | 0.04 | 0.2 | 0.1 |
| Railroad | 0.03 | 0.12 | 0.21 | 0.4 | 1.4 |
| Watershed total | 6.3 | 9.7 | 13.2 | 29.2 | 1.1 |
| Watershed rank value | 2.1 | 3.3 | 4.5 | 10.0 | |

**Storm Runoff.** Although runoff is not a pollutant, it has been shown to be nearly as important as pollutant loading for causing degradation of stream uses. Storm runoff "loadings" in units of acre-inch/inch of rain are presented in Table 7 and Figure 3. Relative differences in storm runoff loadings are similar to those observed for O&G and copper, and high rates of runoff are from intensely developed urban land uses. Table 7 suggests that, as with the urban pollutants, targeting a relatively small area could reduce the overall loading by a substantial proportion. Figure 3 indicates that the same areas contributing high copper loads are contributing high storm runoff rates.

### Evaluation of BMP Alternatives for Butterfield Creek

The methodology report describes several BMP types, including detention, retention, vegetative controls, and source controls. Each of these were discussed briefly in the Butterfield Creek targeting report (3), and that discussion will not be repeated here. The important conclusions from that discussion follow.

The feasibility of implementing certain BMPs differs dramatically between remedial applications (i.e., existing development) and preventative applications (i.e., new development or redevelopment). Most of the municipalities in the Butterfield Creek watershed have recently adopted comprehensive stormwater management ordinances that require implementation of effective detention designs for development activities and require site-by-site evaluation of other BMPs, such as infiltration trenches, filter strips, and vegetated buffers. The ordinance discussed here was developed by the Butterfield Creek Steering Committee.

The limiting cause of stream use impairment in Butterfield Creek is hydrologic destabilization and streambank modification/channelization. After addressing these problems, however, full uses still may not be supported without addressing contributing water quality factors. Thus, BMPs for Butterfield Creek must control both runoff rates or volumes and pollutant loadings.

Stormwater detention is a widely accepted practice in the watershed, and recent experience indicates that the stringent designs that accommodate pollutant removal functions are implementable. The generally accepted detention design for new development among watershed communities calls for limiting the runoff rate for the 2-year storm to 0.04 $ft^3$/sec/acre. This should provide effective pollutant removal as well as control of rates for most storm events. Virtually the only other management practice capable of controlling runoff volumes (and rates) is infiltration (retention devices). This practice, however, has not been widely applied in the watershed or throughout the northeastern Illinois region. The primary constraint to using infiltration practices is the relatively impervious soils of the region.

Most existing detention facilities in the watershed were built without consideration of pollutant removal functions or rate control of more routine events. Investigation of typical facilities, however, suggests that most could be readily retrofitted by installing new outlet controls and performing minor regrading to achieve substantial water quality and rate control benefits. Similarly, there are open areas (e.g., school yards, parks, vacant land) in the watershed where detention could be constructed adjacent to existing uncontrolled developments.

Detention retrofitting has the benefit of controlling both water quality and runoff rate to address stream use impairments as well as flood control benefits, which are often perceived as greater needs. Thus, detention retrofitting has the greatest potential for reducing constraints to stream uses as well as the greatest implementability. Targeting of detention retrofitting is discussed in the following section.

### Reduction of Pollutant and Storm Runoff Loads via Detention Retrofitting

To demonstrate how targeting of BMPs can remediate high pollutant loadings in Butterfield Creek, it was assumed that detention basin retrofitting would be applied to land uses contributing high copper loads. These included industrial, commercial/institutional, and high-density residential uses, representing 16 percent of the total watershed area. For purposes of this evaluation, it is assumed that under existing conditions there is no effective detention-based control of copper runoff from these land uses. This is generally true in that much of the historical development in the watershed occurred without detention requirements. Further, most detention facilities built subsequent to the promulgation of ordinance requirements did not include pollutant removal features. Another significant contributor of copper loads, highways/arterial roads, was not considered for this BMP because of the general unavailability of land within right-of-ways to implement detention.

Targeting is also demonstrated for remediating high storm-runoff rates. Because the same land uses that contribute high copper loadings also contribute the highest runoff rates, the same 16 percent of the area will be targeted for runoff rate control. As with copper, it is assumed that under existing conditions there is no effective control of the 2-year and smaller storm events most affected by urbanization.

Effective detention retrofitting designs, based on fully detaining runoff from the 2-year storm (as now required by most Butterfield Creek communities), was assumed to remove 60 percent of the copper load. Table 8 and Figure 4 show the effects of this action. By controlling

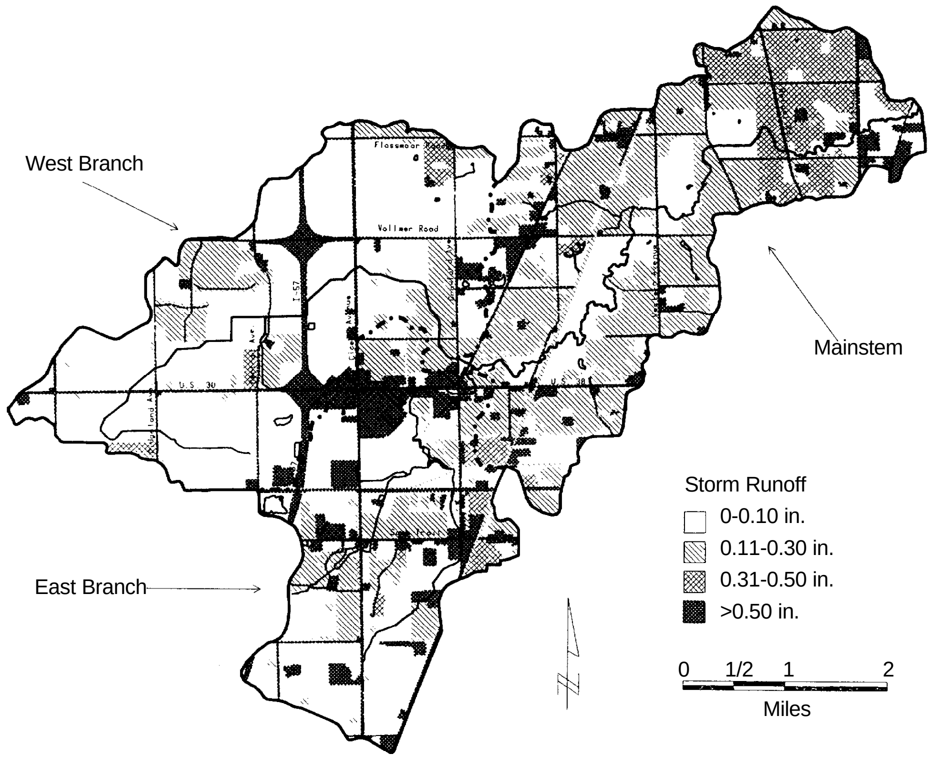


**Figure 3. Storm runoff per inch of rain, Butterfield Creek.**

**Table 7. Storm Runoff (inch-acres per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| **Land-Use Category** | **West Branch** | **East Branch** | **Mainstem** | **Inch-Acres** | **Inches** |
| Industrial | 14.3 | 30.4 | 8.6 | 53 | 0.60 |
| Commercial/institutional | 100.2 | 525.8 | 342.4 | 968 | 0.80 |
| Low-density residential | 171.8 | 175.2 | 516.5 | 863 | 0.20 |
| High-density residential | 58.8 | 48.2 | 423.7 | 531 | 0.40 |
| Vacant | 62.7 | 79.1 | 42.1 | 184 | 0.10 |
| Open land/urban park | 10.9 | 9.7 | 99.3 | 120 | 0.10 |
| Highway/arterial road | 207.7 | 101.8 | 113.7 | 423 | 0.60 |
| Agriculture | 253.0 | 116.2 | 14.9 | 384 | 0.10 |
| Woodland/wetland | 58.5 | 8.8 | 18.2 | 85 | 0.05 |
| Railroad | 2.4 | 10.4 | 18.3 | 31 | 0.20 |
| Watershed total | 940 | 1,106 | 1,598 | 3,644 | 0.22 |
| Watershed rank value | 2.6 | 3.0 | 4.4 | 10.0 | |

just 16 percent of the watershed via detention retrofitting, the total watershed copper load is reduced from 29.2 lb/in. of rain to 19.3 lb/in. of rain, a 34-percent reduction. This example demonstrates quite clearly the value of being able to target BMPs within a watershed.

It is assumed that effective detention retrofitting, which includes control of runoff from the 2-year storm to 0.04 $ft^3$/sec/acre, can limit the storm runoff rates (not volumes) for high-intensity land uses to the runoff rate from nonurbanized land. Table 9 and Figure 5 illustrate the effects of this control being applied to industrial, commercial/institutional, and high-density residential land uses. Comparing Table 7 to Table 9 indicates that the short-term, storm runoff rate is reduced by 35 percent for the entire watershed, from 0.22 in. per in. of rain to 0.14 in. per in. of rain. The reduction in storm runoff rate is even more dramatic for the mainstem (39 percent). In other words, if detention retrofitting can be implemented for just 16 percent of the creek watershed, short-term storm runoff can be reduced dramatically, thereby reducing downstream bank erosion and habitat destabilization effects. While detention retrofitting will have relatively little effect on total runoff volumes, it will dampen stormwater runoff peaks substantially and also produce significant pollutant removal benefits.

## Application of Watershed Prioritization Analysis

The methodology report briefly describes a procedure for prioritizing subwatersheds for BMP targeting. This procedure relies on a number of factors (including water body importance; type, status, and level of use; pollutant loads, and implementability of controls) to rank subwatersheds. The relative importance of these factors is indicated by assigning weights. As discussed previously, the Butterfield Creek watershed orientation is different from the example presented in the methodology report and, as a result, may not be as appropriate for this type of prioritization as the example. Nonetheless, the suggested prioritization methodology is illustrated in the following example.

### *Assignment of Prioritization Factors*

The methodology report recommends the assignment of factors based on relative rankings. For purposes of this evaluation, the ranking scale ranges from 0 to 10.

#### Water Body Importance/Stream Size

Stream size factors are assigned in proportion to the total drainage area providing flow to the stream. Subwatershed drainage area rank values were previously computed and are presented in Table 1.

#### Beneficial Use Type

Use-type ranks are based on the nature of potential use of the stream reach. The mainstem is assigned a relatively high rank because of the presence of riparian public open space and because its size and physical characteristics offer the most potential for aquatic life and recreational uses. The west and east branches are assigned relatively lower ranks because of their more limited potential and because of the perception, particularly for sections of the east branch, that the stream's primary function is drainage.

**Table 8. Copper Loading[a] With Detention Basin Retrofitting for Industrial, Commercial/Institutional, and High-Density Residential Areas (pounds per inch of rain)**

| | Subwatershed | | | Total Watershed | |
|---|---|---|---|---|---|
| Land-Use Category | West Branch | East Branch | Mainstem | Pounds | Pounds/Sq. Mile |
| Industrial | 0.07 | 0.14 | 0.04 | 0.2 | 1.7 |
| Commercial/institutional | 0.45 | 2.38 | 1.55 | 4.4 | 2.3 |
| Low-density residential | 1.17 | 1.19 | 3.51 | 5.9 | 0.9 |
| High-density residential | 0.21 | 0.18 | 1.54 | 1.9 | 0.9 |
| Vacant | 0.14 | 0.18 | 0.10 | 0.4 | 0.1 |
| Open land/urban park | 0.03 | 0.02 | 0.23 | 0.3 | 0.1 |
| Highway/arterial road | 2.35 | 1.15 | 1.29 | 4.8 | 4.3 |
| Agriculture | 0.57 | 0.26 | 0.03 | 0.9 | 0.1 |
| Woodland/wetland | 0.13 | 0.02 | 0.04 | 0.2 | 0.1 |
| Railroad | 0.03 | 0.12 | 0.21 | 0.4 | 1.4 |
| Watershed total | 5.2 | 5.6 | 8.5 | 19.3 | 0.8 |
| Watershed rank value | 2.7 | 2.9 | 4.4 | 10.0 | |

[a]60 percent loads reduction assumed for targeted areas

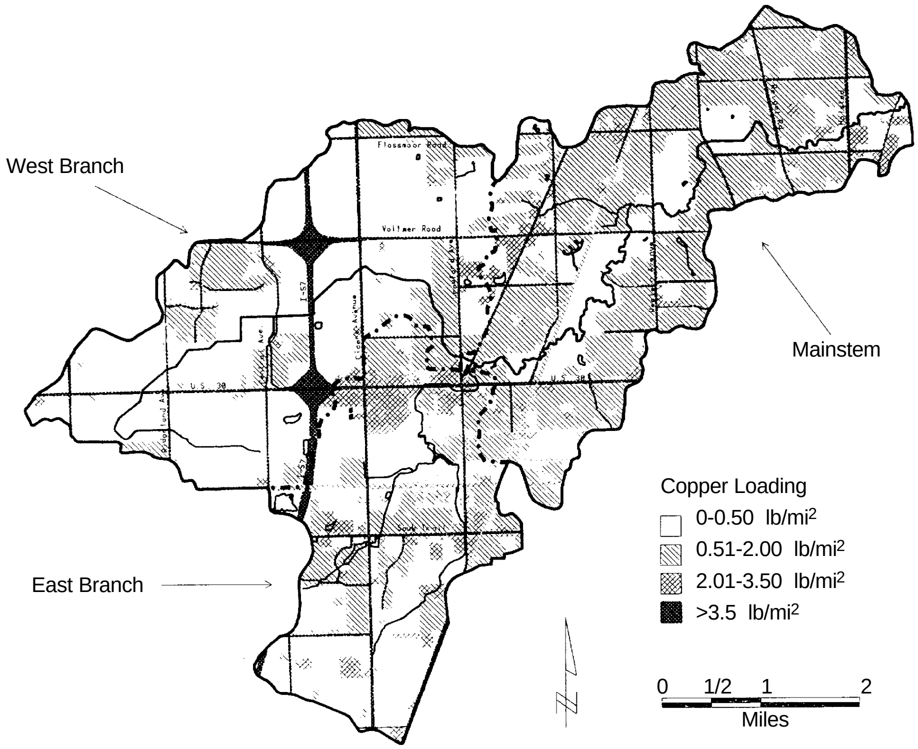


**Figure 4. Copper loading per inch of rain, Butterfield Creek (with detention basin retrofitting for industrial, commercial/institutional, and high-density residential areas).**

**Table 9. Storm Runoff[a] With Detention Basin Retrofitting for Industrial, Commercial/Institutional, and High-Density Residential Areas (inch-acres per inch of rain)**

| | Subwatershed | | | | |
|---|---|---|---|---|---|
| **Land-Use Category** | **West Branch** | **East Branch** | **Mainstem** | | |
| Industrial | 2.4 | 5.1 | 1.4 | 9 | 0.10 |
| Commercial/institutional | 12.5 | 65.7 | 42.8 | 121 | 0.10 |
| Low-density residential | 171.8 | 175.2 | 516.5 | 863 | 0.20 |
| High-density residential | 14.7 | 12.1 | 105.9 | 133 | 0.10 |
| Vacant | 62.7 | 79.1 | 42.1 | 184 | 0.10 |
| Open land/urban park | 10.9 | 9.7 | 99.3 | 120 | 0.10 |
| Highway/arterial road | 207.7 | 101.8 | 113.7 | 423 | 0.60 |
| Agriculture | 253.0 | 116.2 | 14.9 | 384 | 0.10 |
| Woodland/wetland | 58.5 | 8.8 | 18.2 | 85 | 0.05 |
| Railroad | 2.4 | 10.4 | 18.3 | 31 | 0.20 |
| Watershed total | 797 | 584 | 973 | 2,354 | 0.14 |
| Watershed rank value | 3.4 | 2.5 | 4.1 | | 10.0 |

[a]Reduction of runoff coefficient to 0.1 for targeted areas

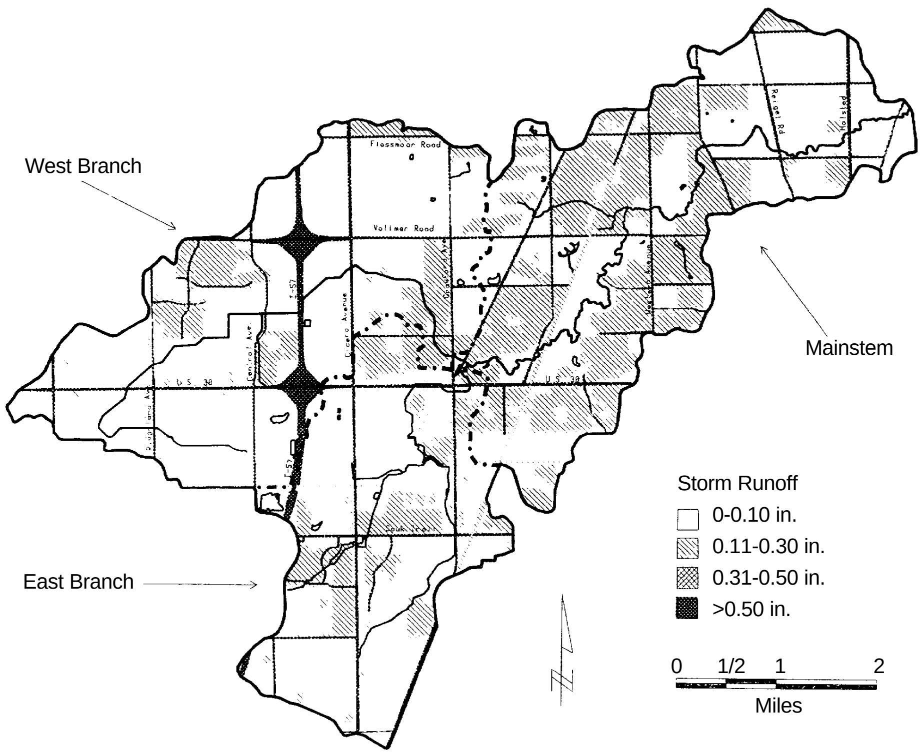


**Figure 5. Storm runoff per inch of rain, Butterfield Creek (with detention basin retrofitting for industrial, commercial/institutional, and high-density residential areas).**

**Beneficial Use Status**

The methodology report is somewhat unclear regarding the determination of this factor. It is assumed in this example that use status reflects the degree of restoration and protection needed to achieve desired beneficial uses. Because each of the branches is similar in its relative degree of aquatic life use impairment, similar factors are assigned. The mainstem's ranking is slightly lower, however, because of the greater level of streamside activities presently supported.

### *Beneficial Use Level*

This factor reflects the level of stream use relative to other water bodies in the target watershed. For Butterfield Creek subwatersheds, use level considers accessible riparian and accessible open space (e.g., parks and golf courses) and the presence of residential land use adjacent to the stream corridor. With these factors considered, the mainstem is assigned the highest ranking, followed by the east branch and the west branch.

### *Pollutant Loads*

This factor represents the degree of pollutant loading or some other cause that is impairing water body use. In this example, runoff rate (rather than quality) is used to reflect this factor. Storm runoff rate factors are derived from Table 7.

### *Implementability of Controls*

This factor is assumed to represent the relative degree of implementability of control measures. In this example, the recommended control measure to reduce storm runoff rates is detention basin retrofitting. As was discussed previously, retrofitting of existing highway/arterial roads probably will not be feasible in most areas. Beyond that, distinguishing the relative implementability of retrofitting based on institutional or technical factors is not easy. For this reason, ranks are assigned on the basis of watershed size and the relative degree of high-density urban development. Another factor that could have been considered is the relative proximity of targeted land uses. Large concentrations of targeted land uses could more readily be addressed through more cost-effective regional controls.

Table 10 presents ranks for each of these factors by subwatershed. It includes an assignment of factors for the total watershed as well. The recommended basis for assignment of total watershed factors is not described in the methodology report. In the Butterfield Creek example, totals of the subwatershed ranks are used for both stream size and stormwater rate. For the remaining

**Table 10. Butterfield Creek Prioritization Analysis**

| Watershed | Stream Size | Beneficial Use: Type | Beneficial Use: Status | Beneficial Use: Level | Stormwater Rate | Ability To Implement | Target Score |
|---|---|---|---|---|---|---|---|
| Weights | 25 | 10 | 10 | 5 | 25 | 25 | 100 |
| West branch | 3.63 | 4 | 7 | 3 | 2.6 | 8 | 4.81 |
| East branch | 2.53 | 3 | 8 | 4 | 3.0 | 4 | 3.68 |
| Mainstem | 3.84 | 6 | 6 | 7 | 4.4 | 4 | 4.61 |
| Total watershed | 10.00 | 5 | 7 | 5 | 10.0 | 5 | 7.70 |

Target score = weighted average of rank points = sum (rank score ∗ weight) / sum (weights)

factors, approximate averages of the subwatershed ranks are used.

### *Assignment of Relative Weights*

The methodology report recognizes that some factors may be more important than others and suggests that these differences be accounted for by assigning different weights to each factor. The report also recognizes that considerable subjectivity is involved in the selection of factors and the assignment of ranks and relative weights.

Discussions with representatives from the watershed, primarily the Butterfield Creek Steering Committee, were considered in assigning relative weights for Butterfield Creek. The actual assignment, however, becomes somewhat challenging for several reasons. First, as indicated, evaluation of the different factors is quite subjective, and quantification, even in relative terms, is difficult. Second, while the listed evaluation factors are clearly important to the efficient remediation of use constraints in Butterfield Creek, they are difficult to compare and weight relative to each other. Third, as discussed previously, because two of the stream branches flow into the third, the remediation of problems in the third branch (the mainstem) is clearly not independent of remedial activities in the other branches. The example from the methodology report does not directly reflect this interdependence.

Bearing in mind these qualifications, weights were assigned to the identified factors by following the procedure described in the methodology report. As seen in Table 10, equal weights of 25 are assigned to the four factors. For the beneficial-use category, weights are assigned to the three subcategories so that they total 25.

### *Results of Watershed Prioritization*

On the basis of the assignment of weights and factors as described above, stormwater rate controls should be applied first to the west branch, followed closely by the mainstem, and then the east branch. Just as in the example in the methodology report, however, the "total watershed" receives the highest target score, implying priority control of the entire watershed.

In evaluating the results of this prioritization to Butterfield Creek, the west branch apparently receives the highest subwatershed priority primarily because it scores quite well in the ability-to-implement category. In reality, its high score in this category is due to the relatively little high-density urbanization within its watershed and, therefore, its relative ease of control. The east branch receives the lowest targeting score because it is smallest in watershed size and because it scores poorly relative to potential beneficial uses.

The interpretation of the total watershed score of 7.7, higher than each of the subwatershed scores, is somewhat perplexing. The procedure applied to Butterfield Creek, which establishes total watershed ranks as averages or sums of the subwatershed ranks, always results in the total watershed receiving the highest score. This implies that problem remediation (or prevention) always should be addressed watershedwide, despite the results of subwatershed prioritization. It also may suggest that the assumptions used in arriving at total watershed ranks are not appropriate and, therefore, the total watershed score should not be compared with the subwatershed scores.

Overall, the results of this simple analysis are quite interesting. Intuitively, if limited funds are available for remedial measures, it makes sense to spend them in subwatersheds in which stream use has the most potential for improvement and in which remedial activities are most implementable. The results for Butterfield Creek, in which the mainstem and west branch receive similarly high targeting scores, are generally consistent with this logic. Because conditions in the mainstem also are dependent on nonpoint contributions from the east branch, however, it may not be possible to eliminate critical use constraints and to fully restore mainstem stream uses without applying effective BMPs watershedwide.

### Other Prioritization Applications

Application of the prioritization in this watershed was not straightforward due to the configuration of the watershed. Based on the experience gained in this application, however, it is apparent that there are two cases in which the prioritization methodology would be more useful and straightforward. The first case would be in prioritizing restoration efforts between separate watersheds under a single management agency or funding source. The second case would be in prioritizing efforts within a single watershed tributary to a critical resource (e.g., recreational lake, high-quality stream segment, water supply reservoir).

#### Prioritizing Between Distinct Watersheds

During development of a statewide or regionwide nonpoint source control program, limited funds often must be prioritized between distinct watersheds within the region. This methodology provides a relatively objective method for assigning priorities to watersheds competing for funds. To ensure acceptance of the results of the prioritization and to avoid conflicts between competing watershed officials, involving the officials and interested parties from all of the watersheds in the assignment of ranking and weighting factors is very important. Because they all have participated in that process and agreed on the ranks and weights, it will be difficult for them to dispute the outcome of the prioritization results. Therefore, a rational schedule can be developed for expenditures and efforts in the various watersheds.

#### Prioritizing Within a Watershed

During development of a watershed nonpoint source management plan, a particular resource within the watershed often motivates development of the plan. The methodology could be used readily to prioritize targeted land uses within that watershed. In this case, however, the beneficial use and probably even the stream size factors would be meaningless because all subwatersheds would be tributary to the same resource whose uses are being protected. The only two factors that would be used would be the pollutant load (or stormwater rate) and the ability to implement.

## Summary and Conclusions

This report has discussed some of the strengths and weaknesses of the urban targeting and prioritization methodology as applied to Butterfield Creek in northeastern Illinois. Highlights of this evaluation are discussed below.

### Technical Representation

The methodology recommends a relatively simple methodology for generating pollutant loads and assessing BMP effectiveness. For purposes of this type of application, which emphasizes relative loadings among land-use types and subwatersheds, this simplicity is appropriate and appears to produce reasonable results for Butterfield Creek. One shortcoming is that the technical procedure is limited to pollutant loads. Inclusion of runoff rates was readily incorporated into the methodology, however, making it more useful for urban streams such as Butterfield Creek.

### Urban Targeting

The urban targeting component of the methodology worked quite well, especially when combined with mapping, which highlighted relative pollutant contributions by land use. Targeting also provided a fairly clear indication of the relative pollutant (and high runoff rate) contributions by subwatershed.

### BMP Selection

Effective BMP selection must take into account the causes of stream use impairment as well as the physical characteristics of the watershed and the drainage system. In the application of the recommended BMP selection methodology to Butterfield Creek, it was clear that BMPs that control both pollutant loads and runoff rates would be required. As a result, detention facility retrofitting became, somewhat by default, the selected BMP for evaluation. The quantification procedure recommended in the methodology report worked quite well and was enhanced by the mapping of pollutant loadings.

### Watershed Prioritization

The application of watershed prioritization to Butterfield Creek, based on assigning ranks and weights to prioritization factors among subwatersheds, was accomplished with some difficulty. Part of this difficulty was related to the subwatershed orientation in Butterfield Creek, in which two stream segments were tributary to a third. The existing methodology is not structured to address this situation. A related difficulty was the subjectivity involved in assigning relative ranks and weights to unrelated prioritization factors. The methodology would be more useful for prioritizing between distinct watersheds or prioritizing within a watershed all tributary to a single critical resource.

### Remedial Versus Preventative Applications

The Butterfield Creek application of the targeting and BMP selection methodology focused on BMPs to remediate existing stream use impairments. This methodology could potentially be applied to assess preventative BMPs as well. In this context, pollutant loads could be assessed for a nonurbanized watershed, for a fully urbanized watershed without BMPs, and for a fully urbanized watershed with BMPs. For a nonurbanized watershed, however, some of the stream-use prioritization factors become irrelevant, assuming that stream use is relatively unimpaired before urbanization. In the Butterfield Creek watershed, several preventative BMPs have already been chosen for newly urbanizing areas. These include soil erosion and sediment control measures, effective stormwater drainage and detention controls, and stream and wetland protection requirements. These preventative BMPs have been endorsed by most watershed communities because of their multipurpose benefits (i.e., nonpoint control, flood prevention, channel erosion control, and aesthetic enhancement) and implementability. Partly for reasons of equity, local officials have no strong desire to target or prioritize these BMPs to particular land uses or subwatersheds.

### *Conclusions*

One of the major benefits of this approach is that the user can document the decision-making process in a systemized fashion. The methodology also forces consideration of the interdependence of various technical and institutional factors in the decision-making process. In addition, the methodology enables the presentation of complex decision-making factors in a visual format. As a result, this methodology could be very useful in targeting BMPs in stream watersheds throughout northeastern Illinois. For successful application of the methodology, however, existing stream use impairments, causes, and nonpoint sources must be clearly understood. In most watersheds, this will require the collection and assessment of additional stream use and water quality data.

The primary limitations of the methodology may be its subjectivity and the fact that it attempts to represent complex watershed interrelationships in a relatively simple fashion. These shortcomings can be addressed by properly qualifying assumptions and providing thorough documentation of results, as well as by involving all of the interested parties in the ranking and weighting process. Without the proper awareness of critical assumptions, however, the methodology is capable of producing misleading or counterintuitive results. Another potential shortcoming of the methodology, revealed in its application to Butterfield Creek, is the difficulty in representing interdependent (i.e., upstream-downstream) subwatersheds and stream reaches.

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# *Development of a Comprehensive Urban Nonpoint Pollution Control Program*

**Jennifer M. Smith and Larry S. Coffman**
**Prince George's County Government, Department of Environmental Resources, Landover, Maryland**

## Abstract

Comprehensive urban nonpoint pollution control is a new, rapidly developing multidisciplinary field. Significant water quality improvements will be achieved when all state and local governments have the necessary resources, knowledge, skills, and vision to implement effective programs. Urban nonpoint pollution has traditionally been addressed by relying heavily on structural stormwater control devices to treat contaminated runoff. Yet, this "band-aid" approach has proven relatively ineffective for controlling such a ubiquitous and poorly defined problem.

The objective of this paper is to illustrate some of the many problems, issues, and obstacles that federal, state, and local government agencies must address to facilitate further advancements in urban water quality control. A more comprehensive, watershed approach must be developed, specifically focusing on source prevention programs, improved technology, and intra-agency coordination. Measuring the effectiveness of innovative source control programs, such as public education, will become essential for targeting problems, focusing goals, and allocating resources to areas needing improvement.

Guidance for implementing these nonpoint pollution control strategies is needed to assist state and local governments. The nature, magnitude, and scope of urban nonpoint source pollution, one of the most fundamental and universal problems facing local governments, are issues that have yet to be adequately resolved. Without program guidance and leadership, the urban nonpoint pollution problem will persist and the quality of our nation's waters will further deteriorate.

## Introduction

To address the complex nature of the national water pollution problem and the comprehensiveness of nonpoint pollution control, all states and municipalities must have access to the understanding, expertise, knowledge, resources, and insight needed to respond to difficult challenges and provide the most appropriate services and solutions. Effective water quality improvement will depend on the ability of municipalities to appropriately implement an array of preventative measures, management strategies, and treatment technologies for dealing with all aspects of water pollution.

Traditional offsite structural treatment is only one of the tools available for addressing this national problem. At the local level a variety of other innovative tools must be tailored to the unique problems and characteristics of a particular site, land use, community, or watershed. Nonpoint source pollution will be fully and effectively controlled only when municipalities understand how to identify problems, evaluate alternatives, and implement solutions.

## Discussion

The magnitude and scope of critical issues associated with current urban nonpoint source control programs, such as the National Pollutant Discharge Elimination System (NPDES) program, must be appreciated to ensure success. To effectively implement the NPDES regulations, municipalities must address the following questions:

### *How Will the NPDES Goals Be Met?*

The success of the municipal NPDES program in achieving the water improvement objectives of the Clean Water Act will depend heavily on the ability and commitment of each municipality to develop focused and effective comprehensive pollution control programs. To reduce nonpoint pollution to the maximum extent possible, local governments must be prepared to support and effectively implement the full range of necessary program components and to shift their programs to a more balanced approach between prevention and treatment.

Municipal governments need active leadership that empowers each jurisdiction with the necessary knowledge, tools, skills, and resources to implement effective programs. Ultimately, each municipality's success will be judged based on the ability to effectively implement program constituents related to planning, coordination, integration, education, prevention, management, maintenance, inspection, enforcement, funding, and appropriate use of technology. Many roadblocks, however, will inhibit the ability to accomplish these objectives. Funding and competition with other local programs are obvious barriers, while misunderstanding the nature of the problem, setting incorrect priorities, and focusing programs on nontraditional prevention strategies are less obvious pitfalls.

### *What Does Each Jurisdiction Need?*

The successful integration of effective nonpoint source pollution reduction programs into traditional local stormwater programs is more easily accomplished if implementation problems are identified and thoroughly addressed. These problems can concern:

- Legal, financial, and political liabilities and issues.
- Public awareness, acceptance, and education.
- Development and implementation of adequate inspection programs for construction and maintenance.
- Development and implementation of effective enforcement programs.
- Funding options for various programs.
- Integration, coordination, and enhancement of existing programs.
- Allocation and sharing of private, public, and corporate resources.
- Understanding the techniques, approaches, strategies, and philosophies of comprehensive water quality planning.
- Development of mechanisms for technology transfer and implementation of innovative practices.
- The need for practical guidance on program development.

Local governments will be looking for guidance on how to overcome these obstacles. Thus guidance on effective model programs must take into account the effect policy decisions have at the local level.

### *Can We Depend on Treatment Technology?*

Historically, stormwater programs have addressed water pollution from a treatment standpoint, making them rather symptomatic and ineffective. Typical programs rely heavily on structural treatment devices to control contaminated runoff from new development. As a result, current water pollution control programs address problems through a "band-aid" approach instead of a more comprehensive approach in which both preventative and treatment measures are employed within a watershed.

With the many years of experience that some municipalities now have using treatment devices, it is becoming clear that many current treatment practices are riddled with inherent problems that may be difficult, if not impossible to overcome. Problems such as burdensome maintenance, improper construction, inadequate design, ineffective site management, and the latest obstacles posed by federal and state wetland permitting requirements have left many local governments frustrated. Thus the proper role, long-term impacts, and effectiveness of current treatment practices in urban nonpoint source pollution control need to be carefully evaluated.

Reliance on treatment technology as the primary approach to pollution control can result in failure of a program. Many current treatment practices cause problems that limit, restrict, or prohibit their use. Thus, in a more recent study, Prince George's County, Maryland, found that of 151 urban nonpoint source treatment devices constructed or put into operation within the past 5 years, only 60 percent were functioning as designed. Given such limitations, it would be inappropriate to guide other local jurisdictions to heavily rely on treatment technology in the hope of greatly improving water quality.

### *Do We Effectively Control New Development?*

One problem that has yet to be adequately addressed is an effective and comprehensive approach to environmentally safe development. Current programs primarily focus on treatment controls for new development and generally do not consider or incorporate other important pollution reduction and prevention strategies.

New development must be designed in such a manner that onsite treatment of stormwater runoff can be effective. In addition, prevention must become an integrated part of site development through public education, implementation of site maintenance and management plans, and industrial process changes.

The goal of an effective stormwater management site plan should be the integration of preventive, management, and treatment devices that can effectively mitigate all adverse water quality impacts associated with the development. New development can be easily regulated and pollution abatement requirements selected from a broad range of options can be imposed, including:

- Greater use of open and surface drainage systems.
- Limited and creative grading to encourage onsite retention and to enhance ground-water recharge.
- Treatment of surface water by maximizing biological, chemical, and physical treatment devices.

- Requiring grounds maintenance plans.
- Education programs for developers and the public.
- Use of effective construction and maintenance inspection and enforcement programs.
- Greater preservation of existing natural water quality and habitat features.

### What Do We Do About Existing Development?

Controlling nonpoint source pollution from existing development represents the greatest challenge but offers the most potential for attainment of overall pollution reduction goals. Water pollution problems associated with existing development are the most difficult to control and require the most complicated mix of approaches. Typical issues include a lack of regulations requiring retrofitting of facilities, a lack of available space to construct onsite controls, limited incentives, difficulty in identifying problems and solutions, a lack of public awareness, a lack of funding, and limited experience with source control and prevention programs. To address these issues, municipalities should consider the following:

- A community and/or watershed-based approach.
- Baseline data collection needs.
- A comprehensive nonpoint source reconnaissance study.
- Investigative approaches and tools.
- Water quality data collection and use.
- Public outreach programs.
- Regulatory actions.
- Inspection.
- Enforcement.
- Comprehensive maintenance and management plans.
- Retrofit opportunities.
- Innovative control technology.
- Lake, stream, and wetland restoration and enhancement.

### How Comprehensive Is Comprehensive?

A comprehensive program not only uses dedicated local government personnel, but also integrates existing programs and personnel at the state and federal level. Coordination, cooperation, communication, and participation among all agencies involved with programs related to water quality improvements are essential for efficient use of available resources.

Many important water quality-related programs have been independently developed over time that achieve a variety of environmental objectives. Identifying all such programs and directing and focusing them on a common goal would be extremely valuable and useful. Although many water quality-related pollution control programs exist, few coordinate oversight in order to pool resources and combine efforts.

Existing water quality protection and community outreach programs can be easily enhanced or expanded to incorporate additional water quality education and enforcement programs. For example, in Prince George's County, the police community relations program is working with the state's Department of Environmental Resources, the U.S. Attorney's Office, and local citizens groups to incorporate water pollution control educational information into the program. In conjunction with a state, federal, and local enforcement training program, this effort focuses on the enforcement of water quality regulations.

The final aspect of a comprehensive program is to consider all possible sources of water pollution, point and nonpoint source alike. Combining the investigation and enforcement efforts of both programs could help eliminate loopholes in the system and facilitate effective use of existing resources. Investigators and enforcement agents at all levels of government must pool their resources and continuously exchange information regarding known sources of water pollution. Leadership will be critical for facilitating such communication and coordination.

### How Will We Measure the Effectiveness of NPDES Programs?

Municipal governments, scientists, environmentalists, and the public will continue to ask, How effective are source controls? Various plans have been discussed as a result of the NPDES stormwater permit application requirements to quantify the effectiveness of municipal programs. Among these is the water quality standards approach that is currently used in the NPDES industrial point source discharge program.

The water quality standards approach to measuring the effectiveness of urban nonpoint source control/prevention programs will require extensive water quality base-flow and storm-event monitoring. In the past, however, water quality monitoring programs, either with automated equipment or manual sampling, have proven to be difficult and costly to implement. Problems with drought conditions, weather predictions, equipment errors, and the physical constraints associated with manual sampling present particular challenges. Ultimately, municipalities, which will be responsible for implementing source control programs and measuring their effectiveness, will need to rely on the availability of low-cost, flexible alternatives.

The success of source control programs will rest on the ability of small and medium-size municipalities to implement comprehensive and effective water quality control programs. How these programs are structured and the number of programs implemented will ultimately determine the effectiveness of urban nonpoint source pollution control efforts. The focus of efforts should not be on the development of water quality standards but on the development and implementation of a wide range of prevention, management, and treatment programs.

## Summary

Significant reductions in urban nonpoint pollution will be achieved only when effective treatment, prevention, management tools, strategies, and programs have been fully developed and implemented. Given the clearer picture of the nature and scope of the problem, how the pieces will fit together is better understood. Nonetheless, effective efforts will require time, patience, and cooperation. All governments, agencies, and organizations dealing with these issues must work together to develop the technology necessary for a nationally comprehensive urban nonpoint source control program. Momentum for change must be sustained by continued strong leadership, and expertise in this ever-growing and complicated field must be appropriately channeled to develop state-of-the-art technology, and not just to restate it.

# *Site Planning From a Watershed Perspective*

**Nancy J. Phillips**
**U.S. Environmental Protection Agency, Region 5, Chicago, Illinois**
**Elizabeth T. Lewis**
**U.S. Department of Agriculture, Soil Conservation Service, Grayslake, Illinois**

## Abstract

The site planning review process involves consideration of the impacts on water resources that can result from the proposed activity, including changes in water quality and quantity. These changes can affect areas immediately adjacent to the site, as well as distant areas of the watershed. Therefore, site-specific and watershed issues must be considered when developing solutions for proper management.

An important first step in the process involves locating the project site within the watershed and becoming familiar with the watershed characteristics. Secondly, analysis of the impact of site development on the resource areas within the watershed should be conducted so that management objectives can be identified. This aids in the identification of best management practices that can meet management objectives for the site and the watershed.

## Introduction

Site planning tends to occur on a limited scale, usually when developing individual sites, such as subdivisions, commercial developments, industrial parks, residential areas, and schools, as well as infrastructure such as roadways and bridges. Together, these sites compose an urban area.

As sites within the urbanizing area develop, water resources such as streams, lakes, wetlands, and ground water degrade. Because of the incremental nature of development and the cumulative effect that development can have on resources, the site planning process must involve consideration of the watershed within which the development is occurring. The watershed approach, which allows for a comprehensive evaluation of the development process, contains several elements that together form a review process: 1) delineation of the watershed and subbasins, 2) inventory of soils, 3) inventory of natural systems, 4) identification of impacts from development, 5) development of management goals and objectives, and 6) development of recommendations for mitigation.

## Delineation of the Watershed

A watershed is an area of land that drains to a water resource such as a wetland, river, or lake. Depending on the size and topography, watersheds can contain numerous tributaries, such as streams and ditches, and ponding areas such as detention structures, natural ponds, and wetlands.

Rainwater and snowmelt that do not evaporate or infiltrate into the soil run off into a nearby tributary or ponding area, then flow to the main wetland, river, or lake within that watershed. Through this linkage, the upper portions of a watershed can affect downstream areas. Thus, the quality of a wetland, stream, or lake often reflects the land use and other activities being conducted in upstream areas. Because the relationship of cause and effect can extend for large distances throughout the entire watershed, it is important to address environmental management issues from a watershed perspective.

Use of topographic maps is a common method of locating and delineating the boundaries of watersheds. To locate a site on a topographic map, the site plan should be closely examined. A topographic map represents the physical features of the land such as hills, valleys, basins, ridges, and channels. The mapping technique used is based on elevation data (usually mean sea level) and contour intervals (commonly of 10 ft). Distinctive features such as road intersections and curves, towns, agricultural field boundaries, streams, and lakes make acceptable landmarks. These landmarks can be used to locate the approximate site on a topographic map. The next step is to delineate the watershed that contains the site. Below is an outline of steps necessary to delineate a watershed:

1. Use a topographic map(s) to locate the river, lake, stream, wetland, or other water bodies of interest (see Figure 1).
2. Trace the watercourse from its source to its mouth, including the tributaries. This step determines the general beginning and ending boundaries (see Figure 2).
3. Examine the lines on the topographic map that are near the watercourse; these are referred to as contour lines (see Figure 3). Contour lines connect all points of equal elevation above or below a known reference elevation. The thick contour lines have a number associated with them, indicating the elevation. The thin contour lines are usually mapped at 10-ft intervals, and the thick lines are usually mapped at 50-ft intervals. Contour lines spaced far apart indicate that the landscape is more level and gently sloping. Contour lines spaced very close together indicate dramatic changes (rise or fall) in elevation over a short distance (see Figure 4). To determine the final elevation of a location, simply add or subtract the appropriate contour interval for every thin line or the appropriate interval for every thick line.
4. Check the slope of the landscape by locating two adjacent contour lines and determine their respective elevations. The slope is calculated as the change in elevation divided by the distance. A depressed area (valley, ravine, swale) is represented by a series of contour lines "pointing" towards the highest elevation (see Figure 5). A higher area (ridge, hill) is represented by a series of contour lines "pointing" towards the lowest elevation (see Figure 6).

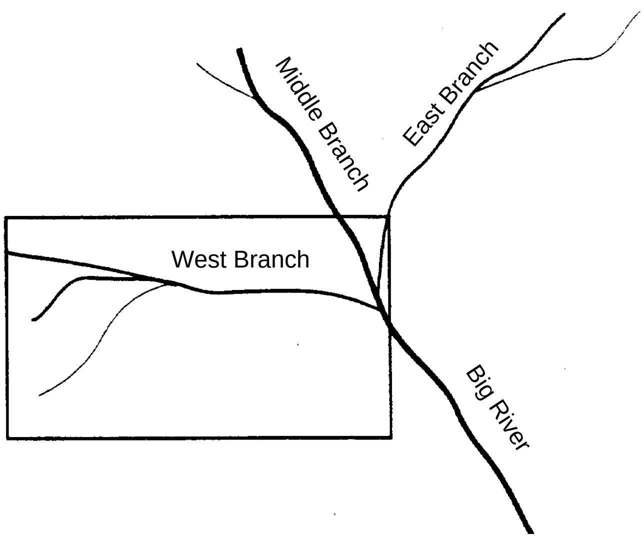


**Figure 1. Big River watershed.**

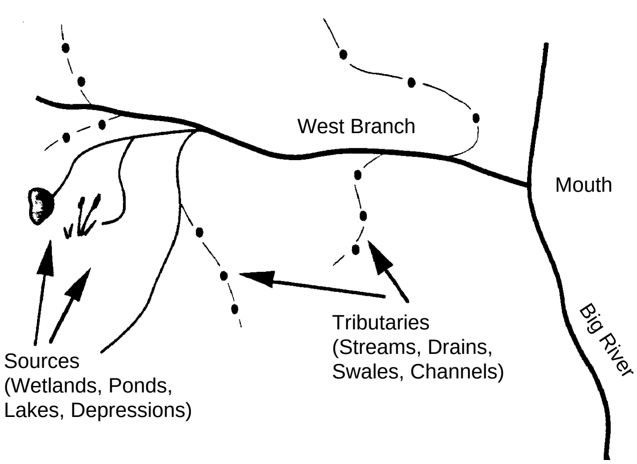


**Figure 2. West Branch subwatershed.**

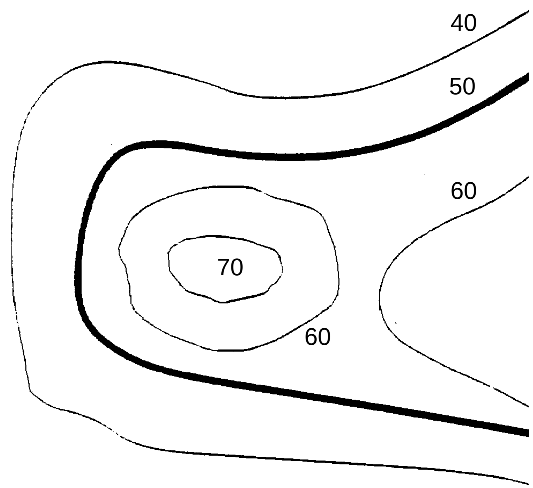


**Figure 3. Contour lines.**

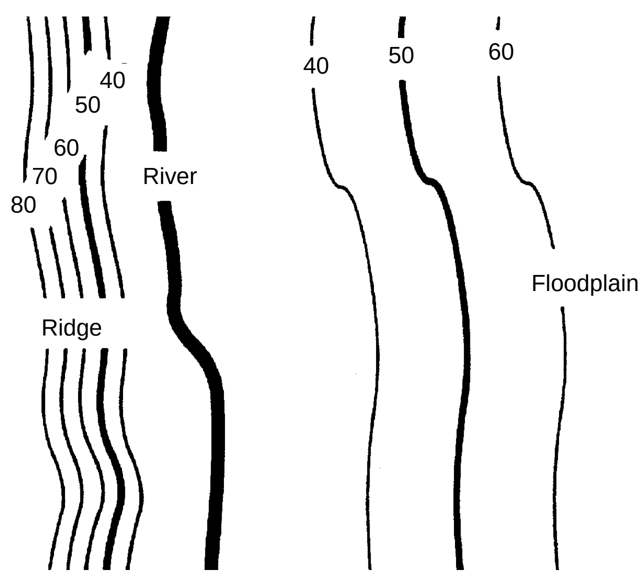


**Figure 4. Floodplains and ridges.**

5. Determine the direction of drainage in the area of the water body by drawing arrows perpendicular to a series of contour lines that decreases in elevation. Stormwater runoff seeks the path of least resistance as it travels downslope. The “path” is the shortest distance between contours, hence a perpendicular route (see Figure 7).

6. Mark the break points surrounding the water body. The “break points” are the highest elevations where half of the runoff would drain towards one body of water and the other half would drain towards another body of water (see Figure 8).

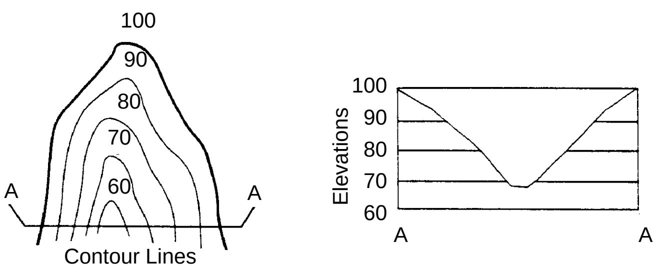


**Figure 5. Valley.**

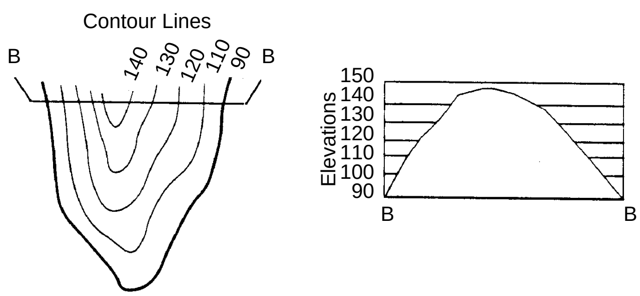


**Figure 6. Ridge.**

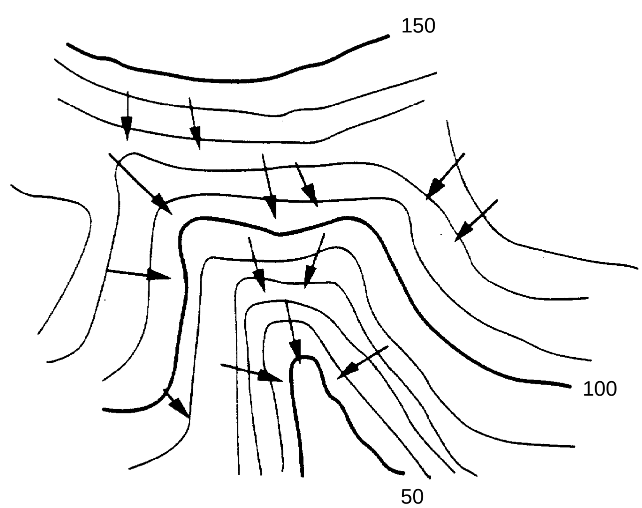


**Figure 7. Direction of drainage.**

7. Connect the break points with a line following the highest elevations in the area. The completed line represents the boundary of the watershed (see Figure 9).

## Inventory of Soils

Locating the site on the soils map requires a U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) soil survey of the county. Select the appropriate soil sheet for the site by examining the *Index to Map Sheets.* Each numbered section corresponds to a soil sheet. After obtaining the necessary soil sheet, locate the site by using distinguishing landmarks, such as road intersections, field outlines, creeks, and rivers. Note the map unit symbols that are in that area. Map unit symbols in a soil survey may consist of numbers or letters, or a combination of numbers and letters. Soil surveys differ from state to state and county to county. Some soils are symbolized by letters and others by numbers. Figure 10 depicts a typical soils map found in an SCS soil survey.

A variety of information that can be used to evaluate sites is contained within the soil survey and maps. The different types of information contained in the soil survey include land capability classification, suitability tables, slopes, erosiveness, wetness, permeability, and drainage patterns.

### *Land Capability Classification*

The land capability classification shows the suitability of the soils for various types of activities, from farming to engineering. The capability classification, denoted by roman numerals, suggests ways to manage and use the soils and highlights any potential hazards. Included in the capability classification are subclasses of erosion, wetness, shallowness, and climate limitations, indicated by small letters after the roman numerals. These subclasses signal a soil’s tendency, for example, towards erosiveness or wetness.

### *Suitability Tables*

Suitability tables are found in the section located after the soil descriptions and management capability groupings. They designate the soil’s suitability for various categories of uses, including wildlife plantings, septic fields, building foundations, and road subgrades. This table can highlight some potential hazards for sites planned on questionable soils. For example, soils that are appropriate for a road subgrade may not always do as well for septic fields.

### *Slopes*

Steepness of slopes can be easily determined by looking for the capital letter posted behind the first series of numbers or letters. The “A” slopes are usually very

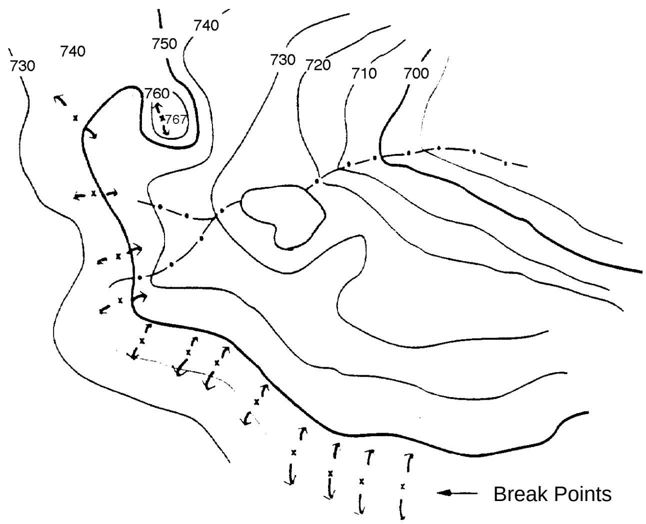


**Figure 8. Identify break points.**

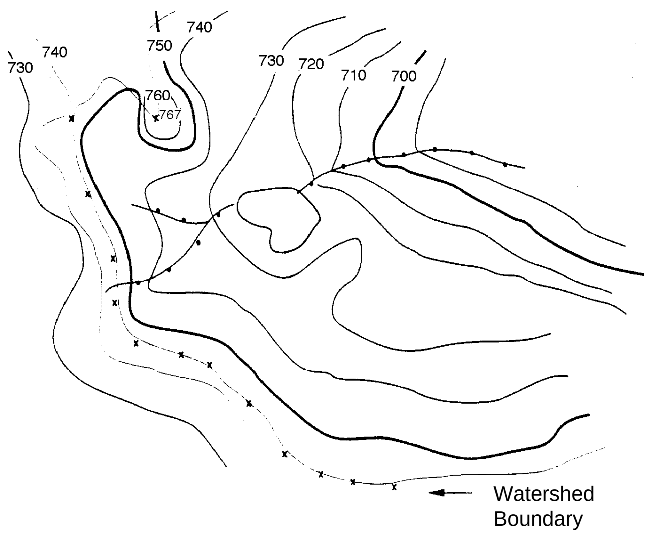


**Figure 9. Watershed boundary.**

**Figure 10. Soils map.**

gentle, with B, C, and D slopes progressively steeper. Knowing the slopes on the site helps determine the amount of grading required and the amount of earth to be moved. Slope steepness also indicates the potential for problems with erosion and stabilization of the site.

### Erosiveness

The soil survey sections entitled “Detailed Soil Map Units” and “Classification of the Soils” provide more specific information regarding the soils and their formations and uses. It is important to scan these sections for any potential erosion problems. Knowing a soil is erosive in nature is useful when analyzing how construction, mass grading, and clearing could affect the site. This can help predict how much soil loss could occur and pinpoint the best erosion and sediment controls to be used on the site. An erosion problem already present on the site may be indicated by the use of a number after the symbol depicting the soil type and slope on the map (e.g., 104B2).

### Wetness

To determine if the soil present on the site is hydric or “wet,” the soil description section and land capability classification indicate whether or not that soil has a water table at or near the surface. Most of the wet soils occur in valley bottoms or depressional areas. On the soil map itself, the wetness may be designated with a “W” preceding or following the soil symbol. Knowing if a soil has a tendency towards wetness can signal potential hazards. A site originally planned for septic systems may have to turn to sewer and water, or a site could contain wetlands that require protection.

### Permeability

Soil permeability is important to a variety of people when looking at a potential construction site. The permeability of the soil can determine if the site is appropriate for a detention pond, a septic field, or an infiltration trench. In addition, knowing if the soil has a slow or fast permeability can alert the planner to the potential for ponding or ground-water vulnerability.

### Drainage Patterns

Soil surveys typically have a smaller scale than a topographic map; therefore, more detail pertaining to the landscape can be shown. Drainage patterns are important to identify. Drainage patterns highlight how the land slopes and drains and in what direction. This is important when considering a site for development, as it is advisable to keep the natural drainage pattern intact whenever possible. Utilizing natural drainage can eliminate the need for regrading and rerouting of runoff from the site.

### Other Information

Other symbols used on a soil survey may denote a wetland or marsh, or the presence of heavy clays, depressional areas, intermittent streams, springs, and erosion spots. These features are not always found on a topographic map. This information is particularly important when doing cursory site evaluations.

The most important point to remember when using the information in a soil survey is to recognize that it has inherent limitations. Due to the scale in the field versus that of an aerial photograph, the soil survey can only point towards a situation that may need further investigation. Any questions raised by the soil survey should be followed by an onsite soil determination by a qualified soil scientist.

## Inventory of Natural Systems

Most areas have National Wetland Inventory (NWI) maps produced by the U.S Fish and Wildlife Service. On the NWI maps, the wetlands are defined as “lands transitional between aquatic and terrestrial systems where the water table is usually at or near the surface, or the land is covered by shallow water.” In addition, the definition requires that one or more of the following three attributes be present: “1) at least periodically the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil, or 3) the substrate is nonsoil and is saturated with or covered by shallow water at some time during the growing season of each year.” Therefore, these maps contain information on sites that have lakes, rivers, and streams, as well as such areas as marshes, bogs, and swamps.

Some counties have advanced wetland mapping that delineates critical areas in need of protection from construction disturbances using the NWI maps as one of their criteria. Recently, SCS has inventoried wetlands in agricultural fields and adjacent areas. In addition, SCS has also identified highly erodible cropland fields. These areas, if developed, will have special needs for soil erosion and sediment control measures.

Other natural systems that need to be included in the watershed review process are ground-water resources, such as aquifers, and recharge areas to public and private wells. Many states have mapped their ground-water resource areas, and local municipalities should have maps showing the location of and contribution zones to public wells.

It is important to examine several additional maps to gain a proper perspective on other developments in the watershed. Comprehensive zoning and plan maps reveal current land use and plans for the future of the area. These maps are invaluable when determining what stormwater best management practices (BMPs) should be applied to the site. If development currently exists upstream or more development is planned, caution may need to be taken when situating homes or businesses near a stream. Conversely, if the proposed development will be upstream of existing developments, detention measures may be needed to prevent downstream flooding. Whatever the situation, knowing where developments are and where they will be helps determine what means and methods of prevention and protection need to be taken.

## Identification of Impacts From Development

Once the locational information for the project has been gathered and the contributing watershed identified, it is necessary to consider the impacts the development will have on the watershed. In general, the major impacts will be alterations in water quality, water hydrology, and terrestrial and/or aquatic habitat. Some simple methods allow initial judgments to be made as to the extent of the impact and the level of mitigation required to protect the surrounding ecosystem (1).

### *Changes in Water Quality*

As people inhabit and use the lands around them, they deposit various pollutants on the land. When rainfall and runoff occur, these pollutants are washed into receiving waters. As urban development occurs within the watershed and the land use changes, pollutants, loading rates, and the concentration of pollutants discharged to the receiving waters also change. Many studies have been conducted during the past 20 years to characterize the types and amounts of pollutants associated with various land uses, including urban land uses. A review of the results indicates that different types of land use generate "typical" pollutants, at amounts within a range of values (2). (These values have been consolidated into a single value based on statistical analysis of all data.)

#### Pollutant Concentration

Some pollutants are more likely to have short-term (acute) effects on environmental systems because of the pollutant concentration. Typically, the pollutants considered to have an acute impact on water quality are oxygen-demanding substances and bacteria. Using an equation that considers normal probability, median pollutant concentrations, and variability, estimates can be made of the probability that pollutant concentrations will exceed acceptable water quality standards. The equations used for estimating concentrations and probability of exceedances are found in Equations 1 and 2 (2).

To estimate expected concentrations, use the equation

$$C_x = C_m (\exp [Z (1n \{1+COV\}^2)^{1/2}]) \quad \text{(Eq. 1)}$$

where (for log-transformed data)

$C_x$ = expected concentration of pollutant x
Z = standard normal probability (for specified probability of occurrence)
$C_m$ = median pollutant concentration
COV = coefficient of variation

To estimate probability, use the equation

$$Z = (\ln[C_x/C_m])/[\ln(1+COV^2)^{1/2}] \quad \text{(Eq. 2)}$$

#### Pollutant Loads

Some pollutants are likely to have long-term (chronic) effects on environmental systems because of pollutant loading rates. Typically, the pollutants considered to have a chronic impact on water quality are nutrients, sediments, toxic metals, organics, and some oxygen-demanding substances. One approach relies on the development of unit area loading rates for various pollutants for different land uses. The unit area loading values are generally a numerical value based on the area of land use (1).

Many methods have been developed to estimate the pollutant load that would be expected from a proposed development. The anticipated value can be compared with the existing pollutant loads to determine the increase in pollutant loading. One of the easiest methods to use is the Simple Method (3). This method uses readily available information but is limited to sites less that 1 square mile in area. Loading information gathered can be used to judge whether some type of runoff treatment will be needed before discharging to the receiving waters. The equation for estimating pollutant loads is found in Equation 3.

When concentration is in mg/L,

$$L = (P) (P_j) (R_v) (C) (A) (0.227) \quad \text{(Eq. 3)}$$

where

L = annual mass of pollutant export (lb/yr)
P = annual precipitation (in.)
$P_j$ = correction factor for smaller storms that do not produce runoff (dimensionless)
$R_v$ = runoff coefficient (dimensionless)
C = average concentration of pollutant
A = site area (acres)

When concentration is in µg/L,

$$L = (P) (P_j) (R_v) (C) (A) (0.000227) \quad \text{(Eq. 4)}$$

### *Changes in Water Hydrology*

As development occurs within the watershed, the degree of imperviousness within the watershed often increases. Impervious surfaces do not allow rainfall to infiltrate as would occur in an undeveloped setting; as a result, more rainfall becomes runoff. As the amount of imperviousness increases, so does the amount of runoff from the site. Taken individually and cumulatively, the increase in runoff will change the hydrology of the watershed. Depending on the location of the site within the watershed and on development conditions in other areas of the watershed, changes in watershed hydrology can negatively affect downstream properties, causing flooding and property destruction, and also lead to downstream bank destabilization, erosion, and scouring. In some areas of the country, land subsidence becomes an issue if the water table is lowered because of the lack of ground-water recharge. This problem can be addressed through ordinances that stipulate all pre- and postdevelopment runoff rates for the entire watershed be considered when a single site is being developed.

A commonly used method for determining the pre- and postdevelopment runoff rates for a site and watershed is SCS Technical Release 55, "Urban Hydrology for Small Watersheds." TR55 can serve as an initial screening procedure for estimating runoff values. An advantage of the procedure is its ease of use through charts and availability on computer disk (4).

### *Alterations in Terrestrial and Aquatic Habitat*

As more undisturbed lands near shore areas are converted into urban and suburban land uses, areas once inhabited by terrestrial and aquatic animal and plant species are minimized or destroyed. As native habitats have continued to decrease over the years, more attention has been given to the need to protect and preserve them. In many areas, endangered species laws serve to protect habitat areas for those plants and animals appearing on state and federal endangered species list. Although this is helpful, it does little to protect more prolific and less sensitive plant and animal species that are burdened by urban development. Consideration of and accommodations for plant and animal species should and can be incorporated into the individual site planning process as well as the watershed management strategy.

## Development of Management Goals and Objectives

An effective method to review site development is to first consider what the overall watershed management objectives are. One place to start looking for this type of information is within the existing state water quality standards. Water quality standards give numerical values and narrative descriptions for various pollutants, at levels that are protective to human and biological health, and assign designated uses for the resource. A management approach can consist of a review of the existing and potential designated uses for the resources within the watershed, and can attain or preserve these uses. In addition, local agencies may have developed management objectives through such mechanisms as watershed protection districts.

A simple hierarchy of management objectives has been presented by Schueler et al. (5), which consists of the following:

- Reducing increases in pollutant loading and concentration.
- Reducing the severity of impacts of pollutant loading and urbanization.
- Addressing specific pollutants.
- Protecting sensitive areas.
- Controlling floods.
- Restoring the area.

Whipple (6) also uses a hierarchical method of designated uses as management objectives:

- Habitat of threatened or endangered species and outstanding natural resource waters.
- Water supply from both surface and ground.
- Other areas to be protected.
- Those not needing protection.

Figure 11 presents a resource area hierarchy consisting of:

- Baseline urban nonpoint source pollutant control
- Baseline urban resource protection
- Control of specific pollutants
- Protection of sensitive resource areas
- Flood control

**Management Objectives**

"Baseline" Urban Nonpoint Source Pollutant Control

"Baseline" Urban Resource Protection

Control of Specific Pollutants

Protection of Sensitive Resource Areas

Flood Control

**Figure 11. Resource area hierarchy.**

## Development of Recommendations for Mitigation

After consideration has been given to the degree to which changes in water quality, hydrology, and habitat alterations potentially affect the watershed and the site and after management goals and objectives have been identified, it is necessary to develop management strategies that mitigate impacts to the level desired. This is accomplished through the use of mitigation techniques, commonly referred to as BMPs. These practices can take the form of engineered practices, called structural BMPs, or nonengineered practices, called nonstructural BMPs. BMPs can be implemented on a site-specific basis and on a regional or watershed basis. The overall management objectives and the severity of impacts from development may dictate the degree of mitigation required (7).

In selecting BMPs for a site, it is important to consider 1) how the BMPs will function as a system; 2) how the practice will meet watershed- and site-specific management objectives, such as pollutant load and concentration reduction, control of storm volumes, and provision of habitat; and 3) what some of the limitations and uses of the practices are.

### *Best Management Practice Systems*

Structural and nonstructural BMPs differ in their design, limitations, and optimal applicability (i.e., addressing pollutant loads, habitat, or hydrology). While some BMPs are implemented to provide a primary objective, secondary mitigation and benefits also are commonly provided. For example, a wet detention pond optimally functions to improve water quality through pollutant load reduction but can also function to balance water hydrology and provide habitat. BMPs can be grouped into discrete functional units that address different aspects of stormwater management. These units are pollution prevention, habitat protection, runoff attenuation, runoff conveyance, runoff pretreatment, and runoff treatment. The units, taken together, form the BMP system. The BMPs selected to meet watershed- and site-specific objectives generally will be from all of these functional units. Figure 12 depicts a BMP systems approach, described below:

- *Pollution prevention:* An effective approach to managing pollutants in urban settings is to prevent or reduce the potential for pollutant loading. Many of the pollution prevention practices are referred to as nonstructural BMPs. These practices can include such activities as public education, zoning ordinances, site planning procedures, restricted use policies, and overlay districts.
- *Habitat protection:* An effective tool for the restoration and management of habitat areas is the implementation of measures to ensure long-term protection. Habitat protection is usually accomplished through nonstructural BMPs, such as river corridor programs, wetland protection programs, critical habitat protection programs, and zoning tools such as open space requirements and creative land-use planning techniques (cluster development).
- *Runoff attenuation***:** One of the most effective ways to manage stormwater flows is to prevent and reduce them. Much of this can be accomplished through a reduction in site impervious cover. Reduction in impervious cover allows for increased infiltration. Other practices that attenuate runoff are drywells, depression storage, and appropriately placed infiltration trenches. Implementing these practices reduces the other impacts of development by reducing runoff volume, flood occurrence, pollutant loads and concentrations, and stream degradation.
- *Runoff conveyance:* Runoff conveyance systems serve to transport the storm flows from the point of origin to the runoff pretreatment and treatment system. Runoff conveyance systems can allow for limited treatment levels, as in the case of grassed swales with check dams and exfiltration devices. Other conveyance systems for stormwater include structural elements, such as pipes with flow splitters.
- *Runoff pretreatment:* Runoff pretreatment is the process whereby runoff is diverted through pretreatment practices. These practices usually prolong and improve the efficiency of the treatment device. Pretreatment practices include vegetated filter strips, riparian systems, settling basins, and water quality inlets.
- *Runoff treatment:* Runoff treatment practices are devices designed to treat stormwater runoff and remove pollutants through a number of processes, including adsorption, transformation, and settling before entry to

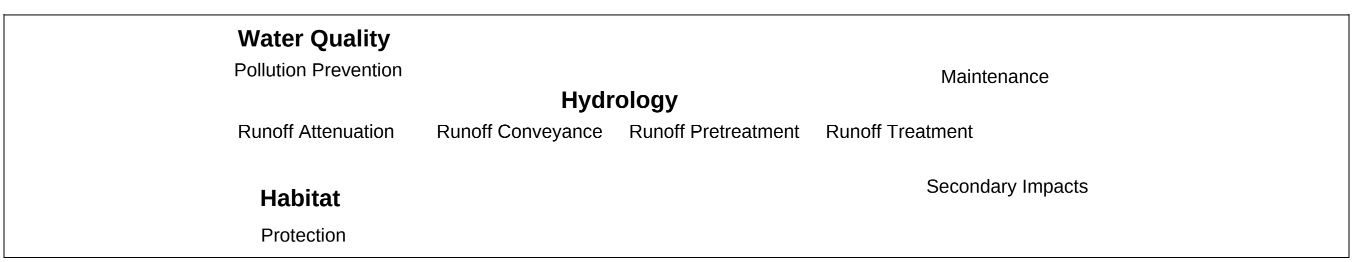


**Figure 12. BMP systems approach.**

the resource area. Treatment devices are considered the final component of the BMP system. Some familiar treatment devices include detention, retention, and infiltration.

Several additional issues need to be considered when developing recommendations for practices. Among these are acceptance of practices by landowners and the aesthetic quality of the practices. Although these issues seem minor, disgruntled landowners can inhibit implementation of effective long-term management programs.

A frequently overlooked but critical consideration for stormwater management is the development of long-term maintenance and financing programs. BMPs, once installed, require upkeep and periodic repairs. Long-term urban runoff management programs require a commitment to maintain technical and program support staff.

### *Determine Reduction or Protection Measures Necessary To Achieve Objectives and Meet Watershed and Site-Specific Needs*

To develop a management strategy, it is important to integrate watershed needs with site-specific needs. The simplest approach is to first consider the broader watershed needs and then "work in" site-specific needs around them. Examples of broad watershed management needs are protecting public water supplies, river corridors and riparian areas, wetlands and wildlife habitat; preserving/expanding open space; or meeting a watershedwide pollutant reduction goal. To address these needs, management practices such as no construction/no disturbance buffer zones, creative site layout practices, impervious cover limitations, tree disturbance restrictions, total site disturbance limitations, and riparian enhancement zones may be utilized. These management practices tend to define or refine areas for the actual site development and site-specific practices.

On the site level, with broader watershed management practices incorporated, more specific needs can be addressed. Examples of site-specific management needs are preventing or managing soils loss, lowering the postdevelopment discharge rate and volume, enhancing riparian areas, and reducing pollutant loads from the site. To address these needs, management practices such as developing and implementing a preventive soil erosion control plan, and installing such items as temporary sediment basins, siltation fencing, dry wells, infiltration trenches, wet ponds, and native plant species planting may be utilized.

It is important to remember that a combination of BMPs is often necessary to achieve desired objectives. No one single practice will provide all necessary mitigation or benefits. Table 1 provides an example of how watershed objectives can direct selection of various practices.

### *Best Management Practice Limitations*

To provide information on the limitations and uses of BMPs, several charts have been developed. The most recently completed of these is found in Schueler et al. (5). Summary information can also be found in Schueler (3) and U.S. EPA (8). Information contained in the charts includes advantages, disadvantages, cost efficiency, limitations for ground-water depth, and soils. Schueler and colleagues consolidated information on reported BMP efficiency in a similar chart form (5). All of this information can help the decision-maker determine the most effective mix of practices to meet stated objectives. Figures 13 and 14 provide an example of the BMP limitation charts available.

## Benefits of Watershed Planning

The most obvious benefit realized from a watershed planning approach is the installation of BMPs to mitigate water management issues before serious problems result. Advance planning saves valuable resources at the state and local level, which could be used in other areas.

Economies of scale can also be realized as a result of the watershed approach. When installing regional practices, larger areas within the watershed can be treated on a per unit area cost basis. This will be beneficial to the development community and the local jurisdictions.

Restoration is always more expensive than prevention. Most restoration costs are associated with damage off site and downstream by runoff and sedimentation. As emphasized earlier, the amount and velocity of runoff flowing off site can cause severe erosion of streambanks and watercourses. Watershed planning can eliminate restoration costs by examining the surrounding area proposed for development. With preliminary runoff control measures, much downstream and offsite damage can be prevented and controlled.

Another hazard of poor planning involves dredging of sediment-laden streams, channels, and lakes. Dredging is a very expensive solution to a problem that could have been prevented for a fraction of the cost. Again, proper examination of an area on a watershed basis can target erosive soils and extensive urbanization with BMPs to keep offsite erosion and sedimentation from occurring.

Mitigation involves creating sensitive habitat areas, usually wetlands, after they have been replaced by filling or construction. Mitigation can often be avoided if some advanced watershed planning is undertaken. By delineating sensitive areas early, alterations in construction plans can be worked around the sites. In planning large areas, sensitive areas can be designated and protected through land acquisitions and greenbelt planning.

Finally, by doing advanced watershed planning the potential for court actions in the case of flooding, erosion

**Table 1. Tools To Achieve Watershed Objective**

| Watershed Objective | BMP System Component | Tools |
|---|---|---|
| Baseline nonpoint source pollutant control | Pollution prevention | Erosion control |
| | | Buffer requirements |
| | | Pesticide/Fertilizer reduction |
| | Runoff conveyance | Grassed swales with check dams |
| | Runoff pretreatment | Vegetated buffer strips |
| Baseline urban resource protection | Pollution prevention | Steep slope restriction |
| | | Site fingerprinting |
| | | Minimum site disturbance |
| | | Cell closure/opening |
| | | Construction phasing |
| | | Erosion control |
| | | Buffer requirements |
| | Runoff attenuation | Infiltration trenches |
| | | Drywells |
| | | Reduced directly connected impervious areas |
| | Runoff pretreatment | Stream buffers |
| | | Wetlands buffers |
| | Runoff treatment | Infiltration basins |
| Specific pollutants | Pollution prevention | Septic system density |
| | | Restricted use areas |
| | | Nitrogen overlay district |
| | Runoff conveyance | Grassed swales with check dams |
| | Runoff pretreatment | Vegetated buffer strips |
| | | Riparian buffers |
| | | Water quality inlets |
| | Runoff treatment | Wet extended detention ponds |
| Sensitive areas | Pollution prevention | Hazardous waste recycling |
| | | Stenciling storm drains |
| | | Industrial cross connections |
| | | Underground storage tank regulations |
| | | Protection districts |
| | | Restricted uses |
| | | Decreased DCIA |
| | | Nitrogen overlay zones |
| | | Septic density requirements |
| | | Extensive erosion/sediment control |
| | | Wellhead protection program |
| | Habitat protection | River corridor program |
| | | Open space requirements |
| | | Cluster development |
| | | Wetlands protection program |
| | | Critical habitat program |
| | | Riparian zone requirements |
| | | Resource area buffer requirements |
| Flood control | Runoff attenuation | Infiltration trench |
| | | Drywells |
| | Runoff conveyance | Riprap swales |
| | | Detention ponds |
| | | Retention ponds |

| BMP | Slope | High Water Table | Close to Bedrock | Proximity to Foundations | Space Consumption | Maximum Depth | Restricted Land Uses | High Sediment Input | Thermal Impacts |
|---|---|---|---|---|---|---|---|---|---|
| Extended Detention Pond | ● | ● | ◑ | ● | ○ | ● | ● | ◑ | ● |
| Wet Pond | ● | ● | ◑ | ● | ○ | ○ | ● | ◑ | ○ |
| Infiltration Trench | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ● |
| Infiltration Basin | ◑ | ○ | ○ | ◑ | ◑ | ○ | ● | ○ | ● |
| Porous Pavement | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| Water Quality Inlet | ● | ● | ○ | ○ | ● | ○ | ○ | ○ | ● |
| Grassed Swale | ○ | ○ | ◑ | ◑ | ● | ● | ○ | ○ | ● |
| Filter Strip | ◑ | ◑ | ◑ | ◑ | ● | ● | ◑ | ○ | ● |

○ May Preclude the Use of a BMP

◑ Can Be Overcome With Careful Site Design

● Generally Not a Restriction

**Figure 13. Other common restrictions on BMPs (3).**

damages, sedimentation removal, dredging, and sensitive habitat areas may be lessened. By looking at the watershed area in total and addressing probable hazards both upstream and downstream, the chances of causing damage downstream will be minimized.

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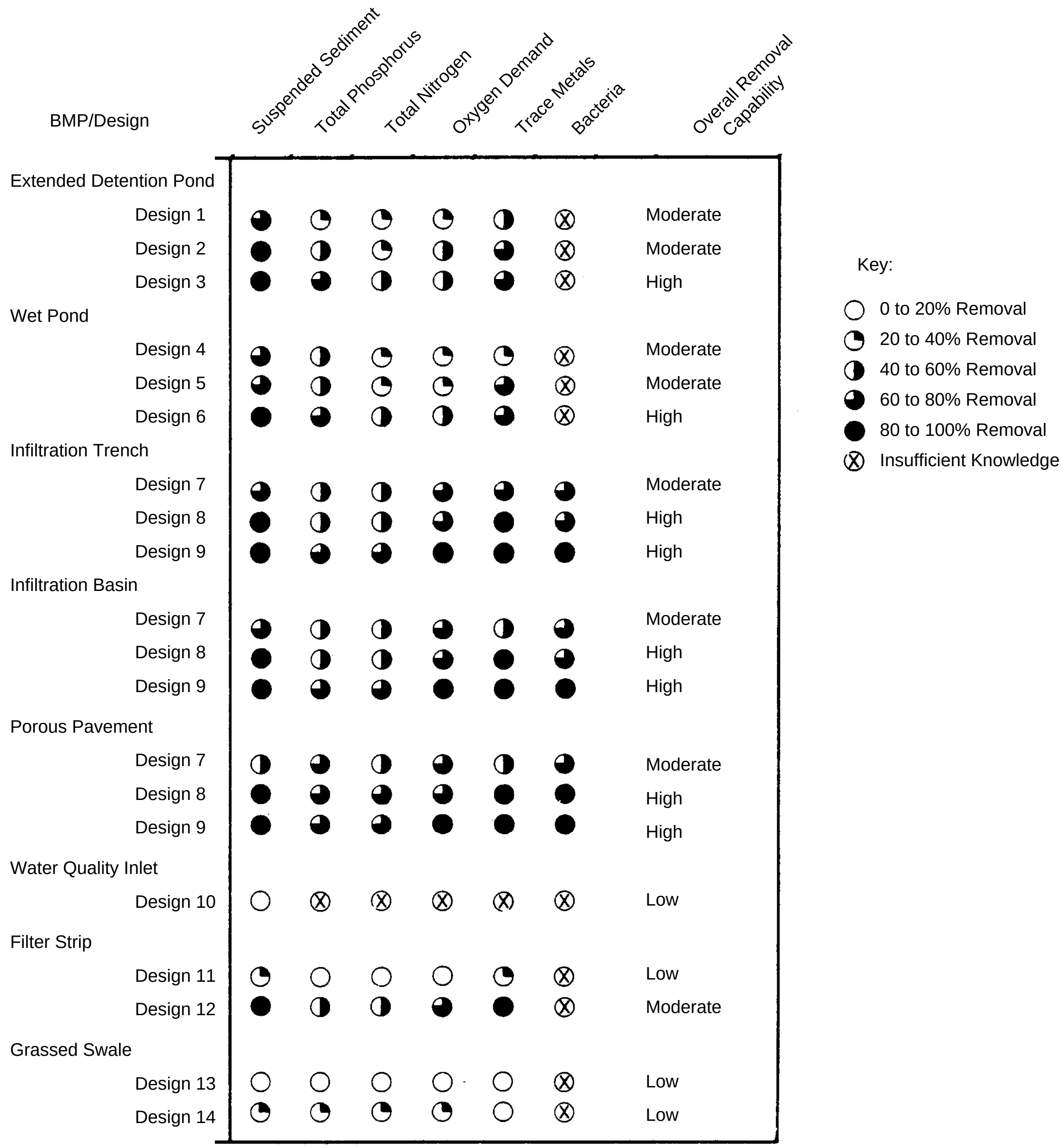


Design 1: First-flush runoff volume detained for 6 to 12 hr.
Design 2: Runoff volume produced by 1.0 in., detained for 24 hr.
Design 3: As in Design 2 but with shallow marsh in bottom stage.
Design 4: Permanent pool equal to 0.5 in. of storage per impervious acre.
Design 5: Permanent pool equal to 2.5 (Vr), where Vr = mean storm runoff.
Design 6: Permanent pool equal to 4.0 (Vr); approx. 2 weeks of retention.
Design 7: Facility exfiltrates first-flush; 0.5 in. of runoff/impervious acre.
Design 8: Facility exfiltrates 1-in. runoff volume per impervious acre.
Design 9: Facility exfiltrates all runoff up to the 2-year design storm.
Design 10: 400 $ft^3$ of wet storage per impervious acre.
Design 11: 20-ft-wide turf strip.
Design 12: 100-ft-wide forested strip with level spreader.
Design 13: High-slope swales with no check dams.
Design 14: Low-gradient swales with check dams.

**Figure 14. Comparative pollutant removal of urban BMP designs (3).**

# *The Soil Conservation Districts' Role in Site Plan Review*

**Glenn Bowen**
**Kent Conservation District, Dover, Delaware**
**Eric H. Buehl and John M. Garcia, Jr.**
**Sussex Conservation District, Georgetown, Delaware**

## Abstract

Officially organized nearly 50 years ago, both the Kent and Sussex Conservation Districts have been at the forefront of soil and water conservation. The more specific role of the conservation districts in sediment control and stormwater management is tied to two legislative initiatives. In 1978, the Delaware State Legislature passed an Erosion and Sediment Control Law (Chapter 40, Title 7, Delaware Code). In 1991, this law was amended to include stormwater management.

Because certain types of construction can increase sediment yields by 2,000 times, sediment control is a necessary first step on any construction site. The conservation districts' role in reviewing site plans is based on the importance of sediment control for limiting the degradation of surface water.

The conservation districts review site plans for stormwater management quantity control to ensure that the risk of downstream flooding is reduced and stream channel erosion is controlled. This is achieved by sustaining predevelopment runoff rates for the 2-, 10-, and 100-year storm events at the postdevelopment state and maintaining similar hydrograph timing for peak flows before and after development.

When reviewing site plans, the conservation districts also consider the quality of stormwater runoff. The order of preference for practices to improve water quality, according to Delaware law, is as follows:  ponds with a permanent pool, extended detention ponds without a permanent pool, and infiltration systems. The acceptability of other practices that can remove up to 80 percent of the suspended solids in runoff is determined on a case-by-case basis. The Kent and Sussex Conservation Districts have promoted sand filtration systems and biofiltration swales for water quality treatment where applicable.

## Background

Delaware, the first state to ratify the Constitution, in 1787, has a rich history dating back to pre-colonial times. Delaware is 1,978 square miles; only Rhode Island has less land mass. Located entirely on the DelMarVa (Delaware, Maryland, and Virginia) Peninsula, Delaware is a 2- to 3-hour drive from Baltimore, Maryland; Washington, DC; Philadelphia, Pennsylvania; and Norfolk, Virginia.

Location between the Chesapeake and Delaware Bays and the Atlantic Ocean provides for a moderate climate. Delaware receives 45 in. of rainfall annually, and Kent and Sussex Counties experience an average of 187 frost-free days a year. New Castle County, the northernmost of the three Delaware counties, is partially located in the Piedmont region, while the rest of the state is in the Atlantic coastal plain. Delaware's gently rolling topography starts at sea level and peaks at 368 ft in the northern part of the state.

With a statewide population of just over 666,000, Delaware has unique demographics. Currently, two-thirds of the population is located on less than one-third of the land in the state. Northern New Castle County, in which the city of Wilmington lies, is within easy commuting distance of Philadelphia and northeastern Maryland.

The city of Dover, located in Kent County in the central portion of the state, is not only the state capital but in 1992 was officially designated a metropolitan area. Kent County, which has considerable land in agricultural production, is also the home of Dover Air Force Base, a central military airlift command facility. Both of these factors have combined to produce considerable growth around the capital city.

Sussex County, the southernmost of the three counties, has two areas of interest that have brought considerable development to a primarily rural area. One is a 25-mile stretch of Atlantic Ocean shoreline. The other area is commonly referred to as the "Inland Bays" region, which has 80 miles of shoreline located directly behind the coastal barrier dune system. Although the resident population of Sussex County is just over 113,000, during the peak of the tourist season (July 4th weekend) the population balloons to an estimated 300,000 people.

In 1969, Governor Russell Peterson assigned a task force to study the steady decline of shellfish and finfish populations as well as related environmental issues of concern for the Inland Bays region. Reports and studies over the subsequent two decades pointed to the necessity of encouraging land-use planning and establishing various water quality initiatives regarding agricultural land and land that could be developed.

Steady growth in the state's metropolitan areas was not surprising. The increasing development in the two more rural counties of Kent and Sussex, however, brought the conservation districts to the forefront of soil and water conservation efforts at land development projects.

## The Role of the Conservation Districts

In their first 50 years, the conservation districts were primarily involved in agricultural issues affecting local landowners. Historically, each district has been run by a board of seven elected supervisors, most of whom are local farmers, and has functioned as a clearinghouse for current information about the construction and maintenance of drainageways, wildlife ponds, and water control structures; updates on the availability of technical and financial assistance for farmers and other residents; and education activities related to resource management and protection.

In 1978, Delaware passed an Erosion and Sediment Control Law covering most types of residential, commercial, industrial, and institutional construction. In 1980, the conservation districts were enlisted to implement the law by the Delaware Department of Natural Resources and Environmental Control (DNREC). DNREC turned to the conservation districts because of their intimate knowledge of the counties in terms of constituents, soils, topography, and local and county governmental structure. Moreover, the conservation districts had a proven ability to run cost-effective programs with a minimum of "red tape."

From 1980 to 1987, development authorities were primarily concerned with erosion and sediment control in regard to all types of new construction. Stormwater management was handled by various state and municipal agencies on an "as needed" basis to control flooding. Then, in 1989, DNREC began the long process of establishing a statewide stormwater management law to address both runoff quantity control and water quality concerns. Using an approach that involved not only the regulators but also the regulated community, DNREC encountered a minimal amount of public opposition and gained the full support of the state legislature.

Thus, on July 1, 1991, the Erosion and Sediment Control Law was amended to include stormwater management. The conservation districts are now the lead agencies implementing this law. The program is considered by many to be a model of efficiency, not only from a cost perspective but also in terms of the rapid turnaround time for plan reviews, which is extremely important for interested parties in this age of fax machines, electronic mail, and cellular phones.

## Scope of Site Plan Review

Review of site plans for construction projects has evolved from mere suggestions provided by a district employee concerning what might work best at a particular location to an engineered topographic plan showing the project's location, the site's details, and specifications for all practices to be used. To illustrate the plan review process, we occasionally refer in this paper to a project for "Running Brook Estates and Business Park" (Figure 1).

Plan review goes beyond looking at blueprints to see that specifications meet minimum standards set forth in state laws and regulations. Material that district inspectors frequently use to assess a project include:

- The state erosion and sediment control handbook.
- The district sediment and stormwater manual.
- County soil surveys.
- U.S. Geological Survey topographic maps.
- Federal Emergency Management Agency floodzone maps.
- State/Federal wetland inventories.
- The Delaware Department of Transportation (DelDot) specification book.
- Equipment manufacturer specifications and literature.

The most important tool for ensuring a thorough design as well as a consistent and efficient review is the management plan checklist. Figure 2 presents the checklist used by the Kent Conservation District.

## Sediment Control

A plan for sediment control and stormwater management usually evolves from the site or grading plan but includes the location, dimensions, and details for the required erosion and sediment controls.

In some cases, designers or developers choose to use the stormwater facility as a sediment trap or basin. This is easily accomplished by modifying the facility's outlet control structure to include the necessary filtration devices (Figure 3). Although use of an infiltration basin

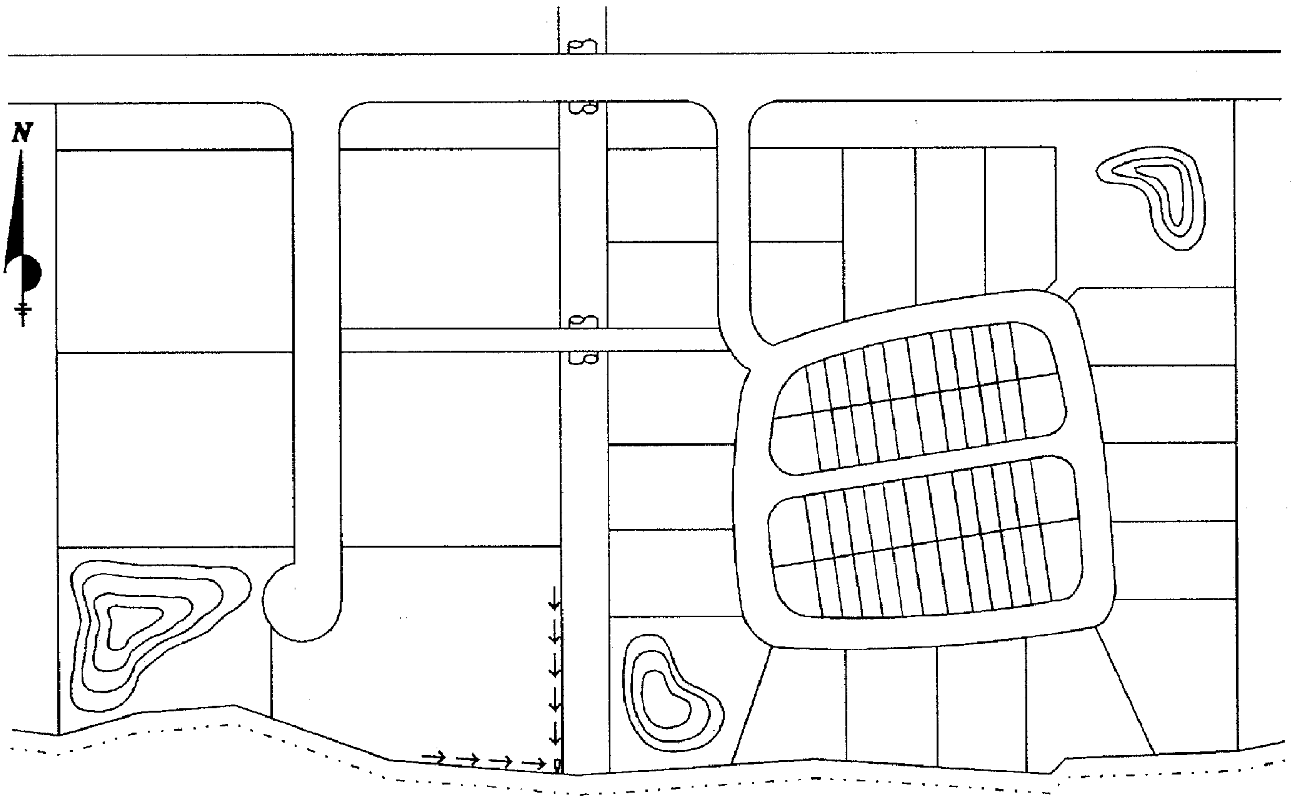


**Figure 1. Site map for Running Brook Estates and Business Park.**

as a sediment trap is generally discouraged, on occasion it may be necessary. For such cases, several approaches are recommended. One is to direct any sediment-laden runoff to a trap (Figure 4, northeast corner). Another is to leave the basin 12 to 24 in. above finished grade until the site is stabilized; excess material is then removed and the basin graded according to the plan's specifications.

The management plan must describe the construction sequence and establish the points at which various control installations must be added, removed, completed, or activated. For certain features, such as embankment ponds, the contractor may be required to notify the district inspector when construction is about to commence. This gives the inspector the opportunity to reemphasize the importance of such aspects of the installations as a cutoff trench and the emergency spillway's dimensions and to visually inspect riser structures, antiseep collars, and the foundation preparation.

Additional sediment control features commonly presented in the plan include the following (see also Figure 4):

- *Rock-check dams:* Used for velocity and erosion control in ditches and swales.
- *Perimeter dikes/swales, earth dikes, temporary swales:* Used to convey runoff to a trap or as a clean-water diversion.
- *A stabilized construction entrance:* Stone structure used to minimize sediment tracking onto roadways.
- *Vegetative requirements list (permanent and temporary):* Used to specify amounts and types of seed, mulch, and soil amendments needed.
- *A silt fence:* Commonly used downstream of disturbed soils as a perimeter filtration device.

Often the review process reveals unique or unexpected site features requiring that the district inspector make additional site visits, hold meetings with designers, and seek technical guidance from the Soil Conservation Service or the DNREC Division of Soil and Water Conservation. For example, because of the unique soils on the DelMarVa Peninsula, erosion problems necessitated that a list of soil erodibility (K) values (Figure 5), as determined by the Universal Soil Loss Equation, be compiled for the predominant soil types shown on the sediment and stormwater plan for Running Brook Estates and Business Park (Figure 6). Such lists not only expedite the review process but also help designers better prepare for the review comment period.

## Stormwater Management for Quantity Control

The adverse impacts of stormwater runoff have been well documented. Damage caused by flooded streams and rivers has cost millions of dollars in property losses and has degraded the quality of the nation's waters. Reducing the risk of downstream flooding and stream-channel erosion after land development is the primary

# KENT CONSERVATION DISTRICT
# SEDIMENT AND STORMWATER MANAGEMENT PLAN

## SUBMISSION REQUIREMENTS

1_____ Review is predicated upon receipt of one set of plans and applicable review and inspection fee.

2_____ Upon notification of approval, one additional set of plans must be submitted to be stamped and kept available on the construction site at all times.

## REQUIRED STATEMENTS

1_____ Provide the name, mailing address, and phone number of the owner of the property, the land developer, the engineer or consultant and the applicant. Provide names of adjacent property owners on the plan.

2_____ Include the following notes:

- A_____ The Kent Conservation District must be notified in writing five (5) days prior to commencing with construction. Failure to do so constitutes a violation of the approved Sediment and Stormwater Management Plan.
- B_____ Review and or approval of the Sediment and Stormwater Management Plan shall not relieve the contractor from his or her responsibilities for compliance with the requirements of the Sediment and Stormwater Regulations, nor shall it relieve the contractor from errors or omissions in the approved plan.
- C_____ If the approved plan needs to be modified, additional sediment and stormwater control measures may be required as deemed necessary by the Kent Conservation District.
- D_____ The Kent Conservation District reserves the right to enter private property for purposes of periodic site inspection.
- E_____ Following soil disturbance or redisturbance, permanent or temporary stabilization shall be completed within 14 calender days as to the surface of all perimeter sediment controls, topsoil stockpiles, and all other disturbed or graded areas on the project site.

3_____ Include signed Owner's Certification of the following statements (<u>these must be signed in ink on each plan submitted</u>):

- A_____ I, the undersigned, certify that all land clearing, construction and development shall be done pursuant to the approved plan.
- B_____ I, the undersigned, certify that responsible personnel certified by DNREC will be in charge of on-site clearing and land disturbing activities.

## GENERAL REQUIREMENTS

1_____ Provide a legend on the Sediment and Stormwater Management Plan.

2_____ Provide a "limit of disturbance" line and the disturbed area in acres.

3_____ Provide a vicinity map with a scale of 1" = 1 mile.

4_____ Provide a north arrow on the plan.

5_____ Maximum plan scale of 1" = 100'

6_____ Plans must be submitted on 24"x36" sheets.

7_____ When two or more sheets are used to illustrate the plan view, an index sheet is required, illustrating the entire project on one 24"x36" sheet.

8_____ Provide existing and proposed contours based on mean sea level datum provided at one foot intervals. Total contributing drainage area must be shown regardless of being located on or off-site.

9_____ For small projects, provide existing and proposed spot elevations on a 50 foot grid system, based on mean sea level datum, with high and low points.

10_____ State and Federal wetlands must be accurately delineated.

11_____ Delineate the National Flood Insurance Program 100 Year Flood Zone.

12_____ Provide soils mapping on plan with a general description of each soil.

13_____ Streams must be delineated.

**Figure 2. Sample sediment and stormwater management plan checklist.**

EROSION AND SEDIMENT CONTROL

1_____ All erosion and sediment control practices shall comply with the Delaware Erosion and Sediment Control Handbook 1989.

2_____ Projects must be phased so that no more than 20 acres is cleared at any one time. Once grading is initiated in one 20 acre section, a second 20 acre section may have stumps, roots, brush, and organic material removed. Grading of the second 20 acre section may not proceed until temporary or permanent stabilization of the first 20 acre section is accomplished.

3_____ Stone check dams are required in all swales, ditches and channels. Provide details, cross sections and specifications, including check dam station locations. Check dam depth must be such that a maximum stone depth is achieved while ensuring that flow will continue over the center of the dam. A minimum 6" depth from the weir to the top of the structure is required.

4_____ All stone, with the exception of check dams, must be underlined by a filter fabric. Filter fabric specifications must be provided for various applications.

5_____ Outlet protection is required at all points of discharge from pipes, channels, and spillways. Provide details, cross-sections and specifications, including d50 stone size, stone depth, outlet dimensions and type of filter fabric.

6_____ Provide inlet and outlet invert elevations for all drainage structures and facilities.

7_____ Provide profiles for all outfall pipes and channels.

8_____ Erosion control matting is required on slopes of 3:1 or greater.

9_____ Provide corner and lowest floor elevations for all buildings.

10_____ Specify what stabilization measures will be used if dust control becomes a problem.

11_____ Sediment traps and basins shall be utilized and sized to accomodate 3600 cubic feet of storage per acre of contributing drainage area until project stabilization is complete. These structures must be located at the base of the drainage area. The following information is required: top of slope, bottom, and outlet elevations, dimensions, proposed and required volumes, type of trap or basin, and contributing drainage area. Include details, cross sections and specifications; a minimum 2:1 length to width ratio is required.

12_____ Diversions must be used to direct runoff into traps. When sediment-laden stormwater is directed to traps or basins by closed pipe systems, temporary diversions must be used to direct stormwater to traps and basins until closed pipe systems are operational.

13_____ Provide a detailed sequence of construction, at a minimum, include the following activities: clearing and grubbing those areas necessary for the installation of perimeter controls, construction of perimeter controls, remaining clearing and grubbing, road grading, grading for remainder of site, utility installation and whether storm drains will be used or blocked until after completion of construction, final grading, landscaping or stabilization, and removal of sediment control practices.

14_____ Soil stockpile areas must be delineated, locate stockpiles on areas with little or no slope. Stockpiles must be surrounded with silt fence or a stabilized earthen berm.

**Figure 2. Sample sediment and stormwater management plan checklist (continued).**

## STORMWATER MANAGEMENT

1______Show drainage calculations considering off-site contributing drainage. Provide pre and post-development velocities, peak rates of discharge, and inflow and outflow hydrographs of stormwater runoff at all existing and proposed points of discharge from the site for the 2 year and 10 year frequency storms. Show site conditions around points of all surface water discharge including vegetation and method of flow conveyance from the land disturbing activity and design details for structural controls.

2______All hydrologic computations shall be accomplished using the most recent version of USDA Soil Conservation Service TR-20 or TR-55, with the Delmarva Unit Hydrograph. The storm duration for computational purposes shall be the 24 hour rainfall event. The pre-development peak discharge rate shall be computed assuming that all land uses in the site to be developed are in good hydrologic condition.

3______Sub-watershed areas must be delineated on the plan for both the pre and post-development conditions. Provide the area in acres of each sub watershed.

4______Provide directional stormwater flow arrows for all existing and proposed channels, pipes, etc.

5______QUANTITY: Post-development peak rates of discharge for the 2 and 10 year frequency storm events shall not exceed the pre-development peak rates of discharge for the 2 and 10 year frequency storm events.

6______QUALITY: Water quality structures having a permanent pool shall be designed to release the first 1/2 inch of runoff from the site over a 24 hour period. Practices not having a permanent pool shall be designed to release the first inch of runoff from the site over a 24 hour period.

## INFILTRATION

1______Infiltration practices shall be used only when the following criteria can be met or exceeded:

- A______Systems shall be designed to accept, at least, the first inch of runoff from all streets, roadways and parking lots. (Including all contributing drainage areas.)
- B______Areas draining to these practices must be stabilized and vegetative filters established prior to runoff entering the system.
- C______A suspended solids filter accompanies the practice, when vegetation is used there shall be at least a 20 foot length of vegetative filter.
- D______The bottom of the infiltration practice is at least 3 feet above the seasonal high water table.
- E______The system shall be designed to drain completely in 48 hours.
- F______Infiltration practices are limited to soils having an infiltration rate of at least 1.02 inches per hour. On site soil borings and textural classifications must be done to verify site conditions and seasonal high water table. This information must be submitted with the plan.
- G______Infiltration practices greater than 3 feet deep shall be located at least 20 feet from basement walls.
- H______Infiltration practices designed to handle runoff from impervious parking areas shall be a minimum of 150 feet from any public or private water supply well.
- I______Infiltration practices shall have overflow systems with measures to provide a non-erosive velocity of flow along its length and at the outfall.
- J______The slope of the bottom of the infiltration practice shall not exceed 5 percent.
- K______Infiltration practices shall not be installed on or atop a slope whose natural angle of incline exceeds 20 percent.
- L______Infiltration practices shall not be installed in fill material.
- M______Unless allowed on a specific project, infiltration practices will only be permitted for the primary purpose of water quality enhancement.

**Figure 2. Sample sediment and stormwater management plan checklist (continued).**

PONDS

1_____ All ponds constructed for stormwater management shall be designed and constructed in accordance with USDA Soil Conservation Service Small Pond Code 378, dated September 1990, as approved for use in Delaware.

2_____ All ponds shall have a forebay or other design feature to act as a sediment trap, a 10 foot reverse slope bench must be provided 1 foot above the normal pool elevation for safety purposes, a 10 foot level bench 1 foot below the normal pool elevation, and all embankment ponds having a permanent pool shall have a drain installed.

DETAILS

1_____ Provide details and specifications for all erosion and sediment control and stormwater management practices used.

2_____ Provide details of temporary and permanent stabilization measures.

3_____ Provide details, cross-sections and specifications (including stabilization) for diversions, ditches, ponds, swales, infiltration structures, etc.

4_____ Specify details of any unusual practices used.

MAINTENANCE

1_____ Specify whose responsibility it will be to maintain and repair all erosion and sediment control and stormwater management practices during utility installation.

2_____ Maintenance set aside areas for disposal of sediments removed from stormwater management facilities must be provided. Set aside areas shall accomodate at least 2 percent of the stormwater management facility volume to the elevation of the 2 year storm volume elevation, maximum depth of set aside volume shall be 1 foot, and the slope of the set aside area shall not exceed 5 percent.

3_____ A clear statement of defined maintenance responsibility shall be established during the plan review and approval process.

**Figure 2. Sample sediment and stormwater management plan checklist (continued).**

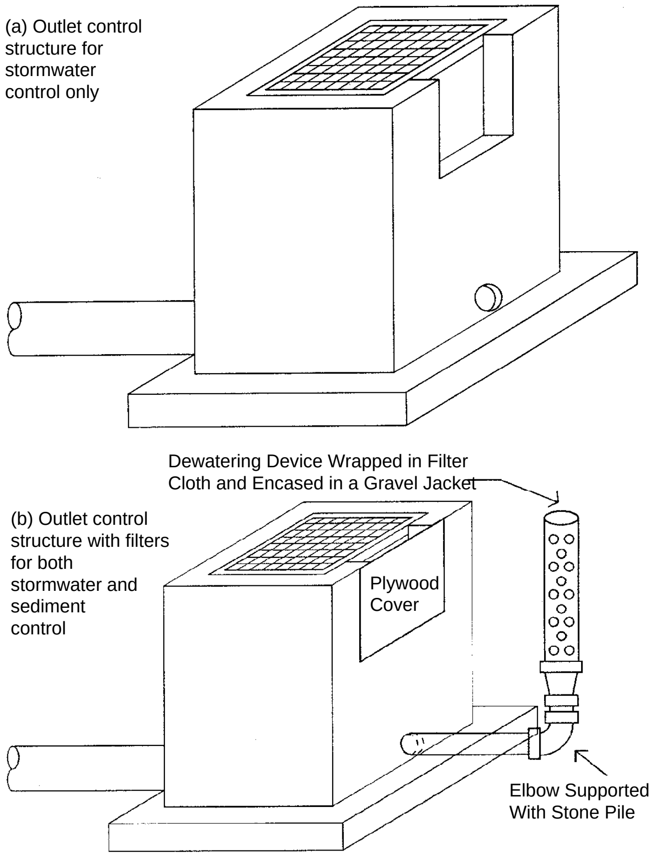


**Figure 3. Outlet control structures for sediment and stormwater control.**

reason for establishing a program that encourages stormwater management quantity control. Indeed, it has also been shown that flood peaks after development can increase by more than 500-fold.

The conservation districts' role in stormwater management quantity control is to ensure that discharge rates for the 2- and 10-year, 24-hour duration storm events do not increase following development. The districts also review management plan data on hydrograph timing and runoff volumes to ensure that areas downstream of development sites are not adversely affected. The districts prefer multiple-storm control because it is generally accepted as the most appropriate management approach for a wide range of storm discharges.

To compute stormwater discharges, procedures described in the Soil Conservation Service's Technical Release (TR) 20 and TR55 are used. Along with being generally user friendly, TR20 and TR55 procedures facilitate the production of required hydrographs and the computing of runoff storage requirements. Sussex and Kent Counties—and the DelMarVa Peninsula generally—fall under the TR20 and TR55 Type II rainfall distribution.

Early in the model's development, concerns were expressed that this rainfall distribution did not accurately represent the DelMarVa Peninsula, with its generally gently rolling topography, sandy soils, and limited outfalls. As a result, studies were performed and a new

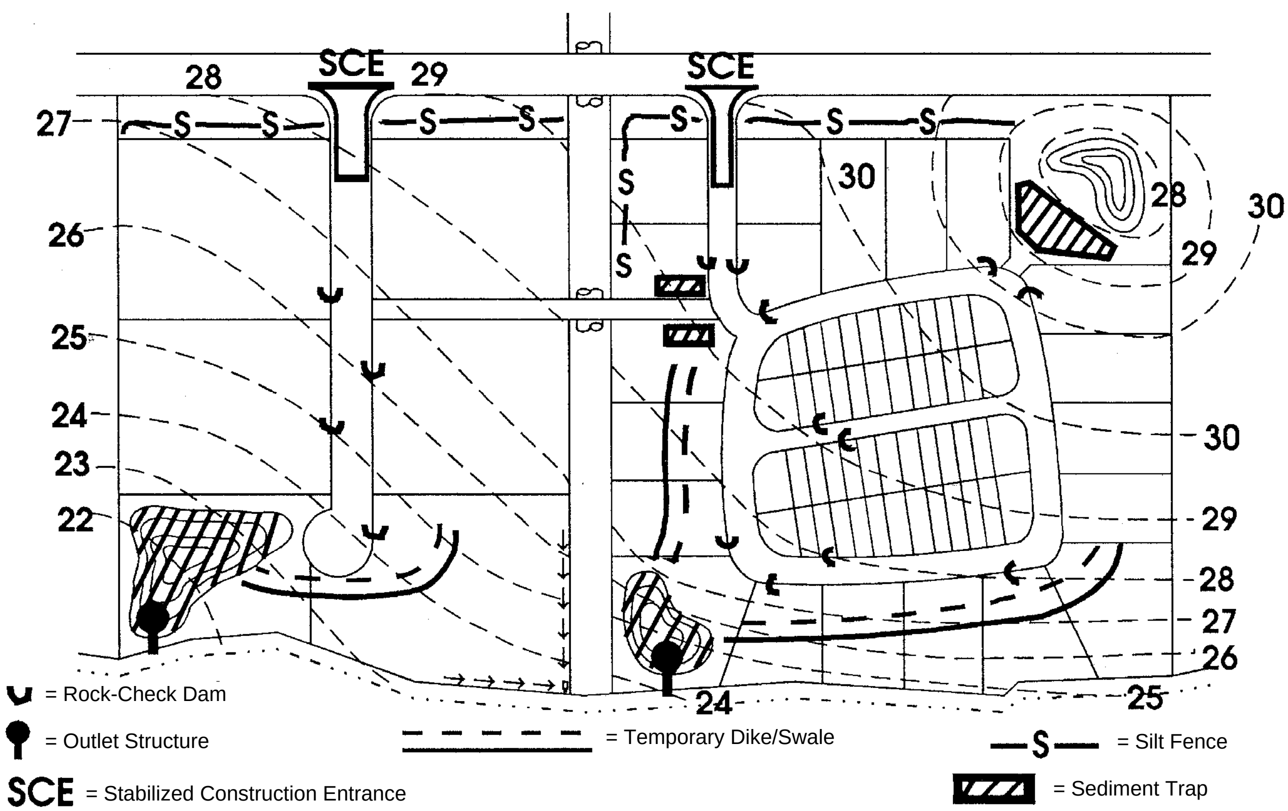


**Figure 4. Sediment control features at Running Brook Estates and Business Park.**

**Sussex Conservation District**
P.O. Box 8 : Georgetown, Delaware 19947 · Phone (302) 856-2105 or 7219

## LIST OF HIGHLY ERODIBLE SOILS*

*S.C.S. FIELD OFFICE TECNNICAL GUIDE ("K" VALUE OF 0.20 OR GREATER)

| SOIL NAME | SOIL SYMBOL | "K" VALUE | |
|---|---|---|---|
| ELKTON SANDY LOAM | El | 0.43 | |
| ELKTON LOAM | Em | 0.43 | |
| EVESBORO SAND (0-15%) | EoB-D | 0.43 | |
| FALLSINGTON SANDY LOAM | Fa | 0.28 | |
| FALLSINGTON LOAM | Fs | 0.28 | |
| KALMIA SANDY LOAM | Ka | 0.28 | |
| KENANSVILLE LOAMY SAND (0-5%) | KbA/B | 0.24 | |
| KEYPORT FINE SANDY LOAM (0-5%) | KfA/B2# | 0.43 | #ERODED |
| MATAWAN LOAMY SAND | Mm | 0.28 | |
| MATAWAN SANDY LOAM | Mn | 0.32 | |
| POCOMOKE SANDY LOAM | Pm | 0.28 | |
| PORTSMOUTH LOAM | Pt | 0.28 | |
| RUMFORD LOAMY SAND (0-10%) | RuA-C | 0.20 | |
| SASSAFRAS SANDY LOAM | SaA/B/C2#/D | 0.28 | #ERODED |
| SASSAFRAS LOAM (0-5%) | SfA/B | 0.28 | |
| WOODSTOWN SANDY LOAM | Wo | 0.28 | |
| WOODSTOWN LOAM | Ws | 0.28 | |

**Figure 5. Erodibility values for predominant soils on the DelMarVa Peninsula.**

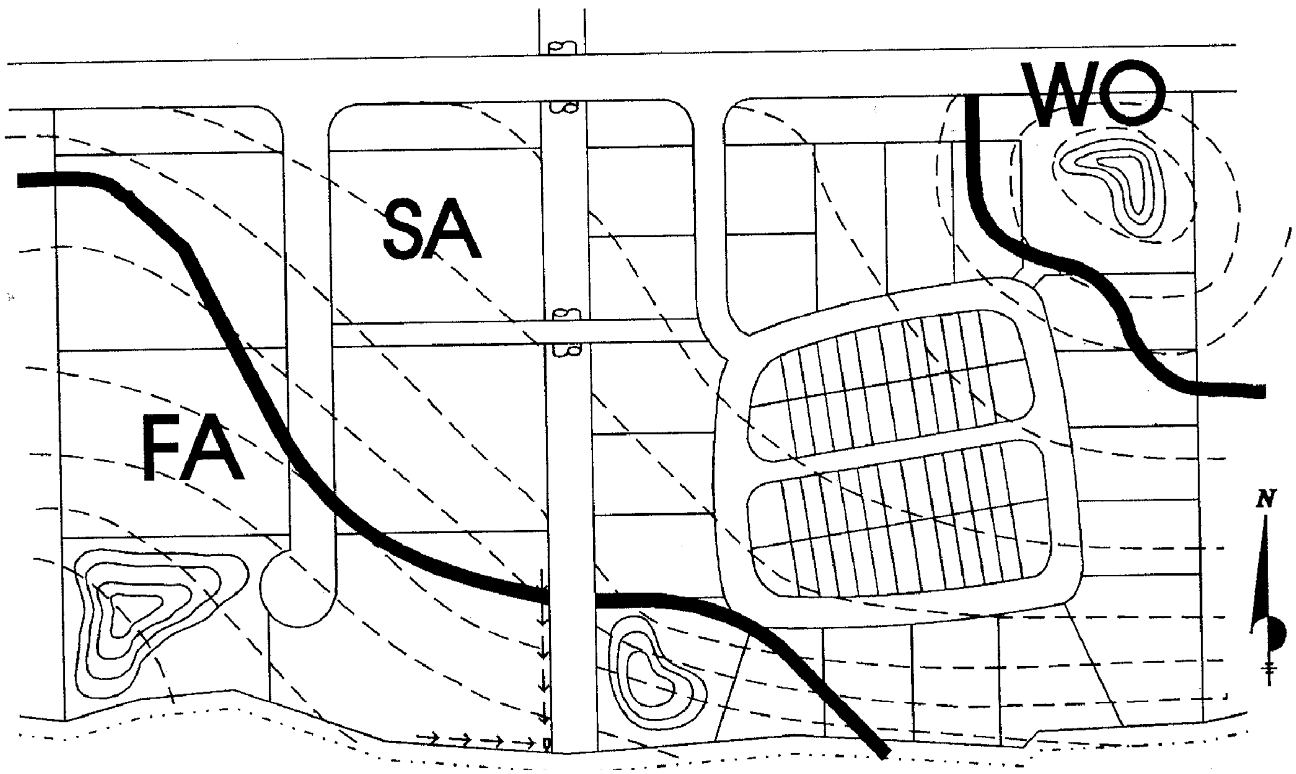


**Figure 6.** **Predominant soils at Running Brook Estates and Business Park.**

dimensionless, synthetic unit hydrograph was developed to be used with the Type II rainfall distribution. This hydrograph, named the DelMarVa Hydrograph, is used in Kent and Sussex Counties. The DelMarVa Hydrograph can develop peak flow rates up to 60 percent of those using just the given dimensionless synthetic hydrograph with the Type II rainfall distribution.

Stormwater is primarily managed for quantity control with ponds. In the Running Brook Estates and Business Park example, three stormwater management ponds are used (see Figure 7). The two ponds at the south side of the site were sized in accordance with standard criteria (i.e., using the 2- and 10-year, 24-hour duration storm events for discharge rates). The third pond is sized for a watershed with no positive outfall, a unique situation that often exists on the DelMarVa Peninsula. In such situations, when all possibilities to achieve an outfall have been exhausted, the facility is sized for the 10-year storm event runoff volume. A modified 100-year flood zone is then determined to establish finished floor elevations for any properties that could be affected by storms larger than the 10-year event. Infiltration can be factored in to reduce the size of such structures.

When development is proposed in urban areas and site space is limited, the district inspector has the flexibility to reduce the stormwater management quantity requirements to those related to quality, as discussed in the next section.

## Stormwater Management for Quality Control

The preferred method for water quality treatment is use of a retention, or "wet," pond. Such a pond has a permanent pool capable of holding up to 1/2 in. of runoff over the drainage area. The elevation of the pool is determined by the low flow orifice of the outlet structure (Figure 3), from which the first 1/2 in. of runoff flows. Thus, above this elevation, 24-hour extended detention is provided for the 1/2 in. of runoff. Another feature required in the construction of a wet pond is the level bench. The bench is a 10-ft wide ledge around the perimeter of the pond, approximately 1 ft below the design elevation of the permanent pool, on which vegetation may be planted or allowed to grow naturally. The establishment of a thick mat of vegetation offers water quality improvements through sedimentation, filtration, and nutrient uptake. In addition, once this marshy area is established, it may help deter public access to the permanent pool area. Conservation districts often encourage addition of a wet pond as a water quality measure when soil and ground-water conditions are appropriate.

Figure 7 shows a wet pond in the southwest corner of Running Brook Estates and Business Park that was installed to capture and provide water quality treatment for a majority of the site's runoff. The pond's irregular shoreline and its proximity to wetlands (south of the site) make the pond aesthetically appealing and provide an

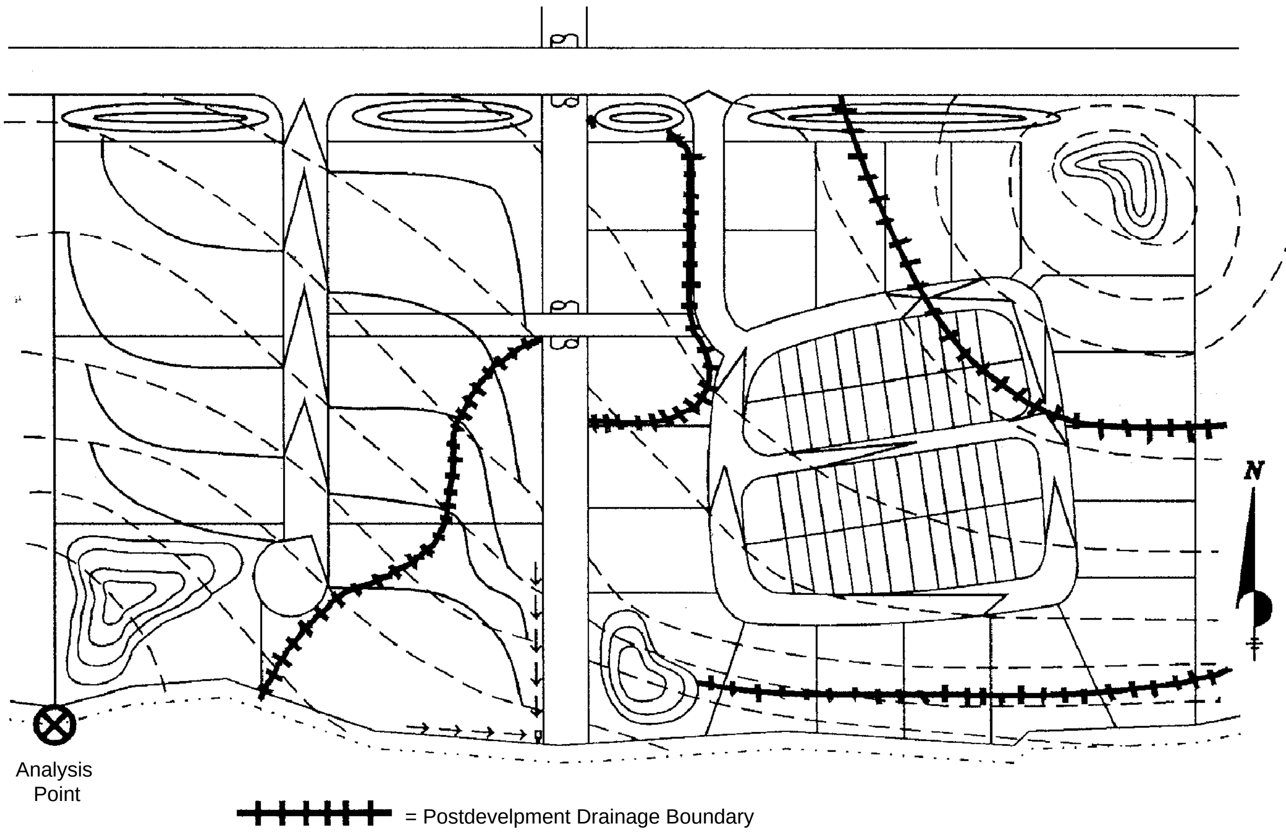


**Figure 7. Stormwater management ponds at Running Brook Estates and Business Park.**

extension of the natural area. Picnic tables were placed in the area for tenants' use.

More common for new construction projects is the detention, or "dry," pond, which detains runoff during a storm but then drains completely to a dry state. To meet regulations, a dry pond must be designed with a low flow orifice that provides extended detention of the first inch of runoff for a 24-hour period. While this appears to be an increase from the 1/2 in. required for wet ponds, actually the reverse is true. The first flush is generally accepted to be the first inch of runoff, but because wet ponds have been shown to provide better sedimentation and nutrient uptake, a volume credit is given for the use of a wet pond. This reduces the extended detention requirements by 50 percent.

Figure 7 shows a pond at the southern edge of Running Brook Estates and Business Park that provides extended detention for runoff from a large portion of the residential development. Discharge is to the wetland areas south of the site. Based on studies by the Mercer County Conservation District in New Jersey, the bottom and sides of this pond need to be planted with a wildflower mix. This type of vegetation will reduce the necessity of mowing to once a year, in the fall, greatly reducing maintenance expenses and increasing visual appeal. While state law requires a 3:1 side slope ratio for ponds in residential areas, the conservation districts encourage owners and consultants to design milder slopes.

If the use of ponds is not feasible on a site, an infiltration system should be considered. Infiltration trenches, in which perforated pipe is placed on a stone bed surrounded by filter fabric, are often preferred for urban sites, where higher land values make such systems particularly cost efficient. Infiltration trenches are generally considered less cost-effective for larger sites.

Another type of infiltration system is the basin. The infiltration basin depicted in the northeast corner of Running Brook Estates and Business Park in Figure 7 is used for the no-positive-outfall situation described above. The infiltration method of runoff management is encouraged for water quality enhancement but is discouraged for water quantity control due to the high potential for failure.

State law also allows the use of any practice that can achieve 80-percent removal of suspended solids in stormwater runoff. One such practice, the use of sand filters, has been effective in Delaware. Sand filtration can also be effective for capturing hydrocarbons, which can escape from ponds. Such systems function much like a septic system, with a sediment chamber leading to a filtration chamber (Figure 8); however, the majority of runoff is stored ahead of the structure in two grassed swales. Because this design is new, a strict maintenance schedule has been developed that must be followed until

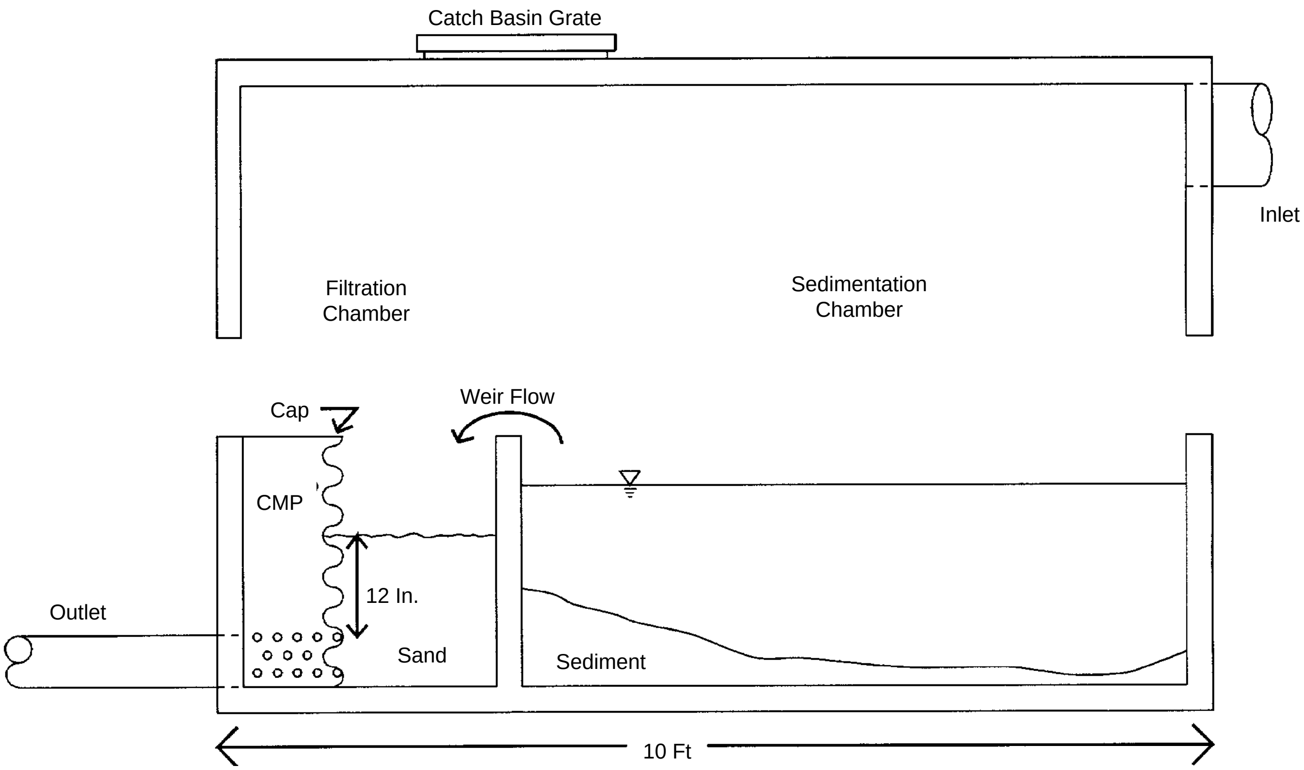


**Figure 8. Septic tank modified for sand filtration.**

performance can be verified. The system must be inspected every 3 months and any large debris removed. Once a year, the sedimentation chamber must be evaluated and the polluted top layer of sand removed and replaced. Every 5 years, the entire volume of sand must be replaced.

Another acceptable method of infiltration is the use of vegetated swales, an approach referred to as biofiltration. Given their linear configuration, vegetated swale systems may be especially appropriate for space-limited urban sights where a water quality pond might otherwise be used.

Runoff from the northwest corner of Running Brook Estates and Business Park is treated in two biofiltration swales before it enters the tax ditch that separates the residential subdivision from the business park. The swales are located on either side of the forestry lane leading to the tax-ditch crossing. The forestry lane, which was installed because fire laws require two access points for developments of this size, is demarcated with a combination of fescue and a wildflower mix, which the conservation district mandates for the quality and aesthetic aspects of swales.

Because these swales at Running Brook Estates and Business Park only receive water quality treatment, a TR20 analysis was performed on the entire site to assess flows at the analysis point shown in Figure 7. Other factors were also considered in finalizing review of the site plan (see Figures 9, 10, and 11).

## Site Inspection

Plan review is not the only element of sediment control and stormwater management delegated to the conservation districts. To keep day-to-day operation of the program within one agency, the conservation districts also conduct site visits periodically during construction and then on an annual basis to perform maintenance inspections of all completed facilities. A long-term maintenance plan for each facility, identifying the responsible parties, must be established during the plan review stage.

## Conclusion

The most important role the conservation districts have in site plan review is providing technical assistance to landowners, designers, and contractors with respect to sediment control and stormwater management. The districts' staff pride themselves on their working relationships and knowledge of the evolving situations in the state's counties.

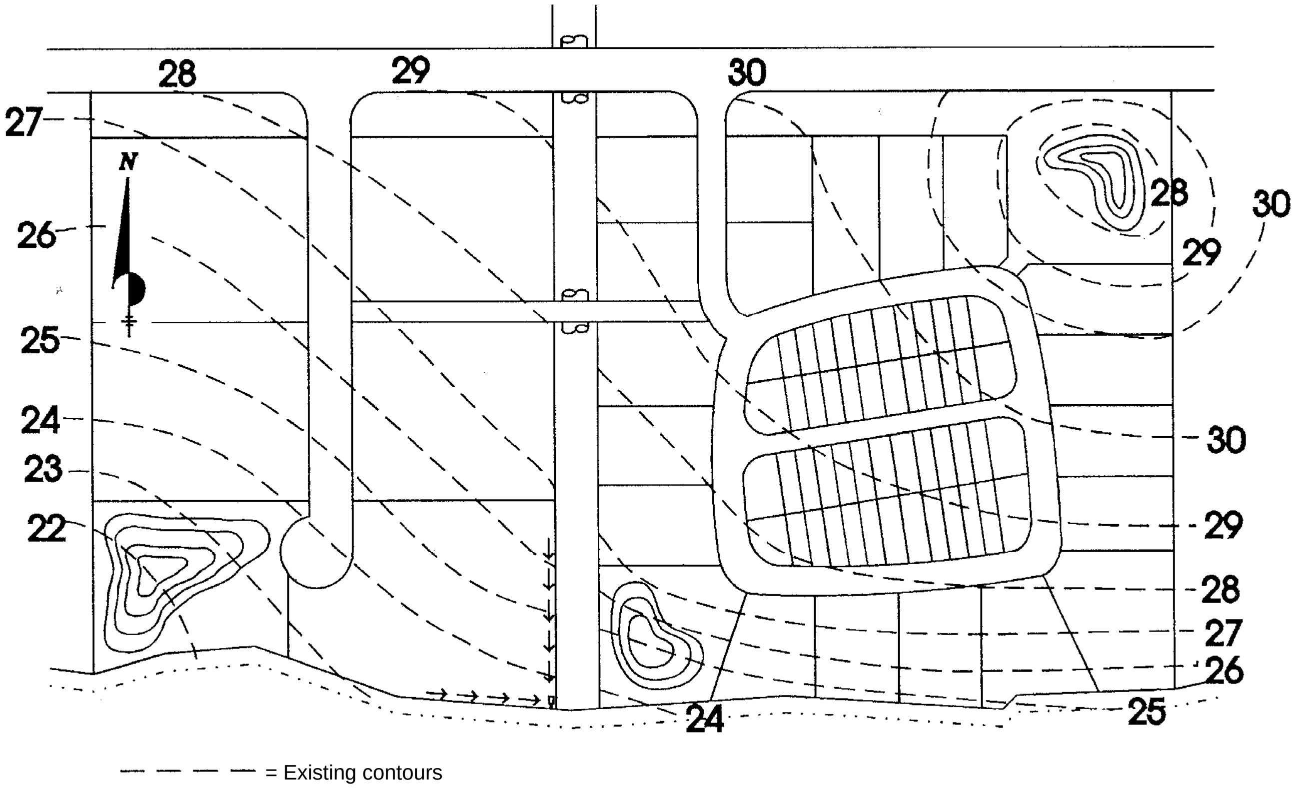


**Figure 9. Existing contours at Running Brook Estates and Business Park.**

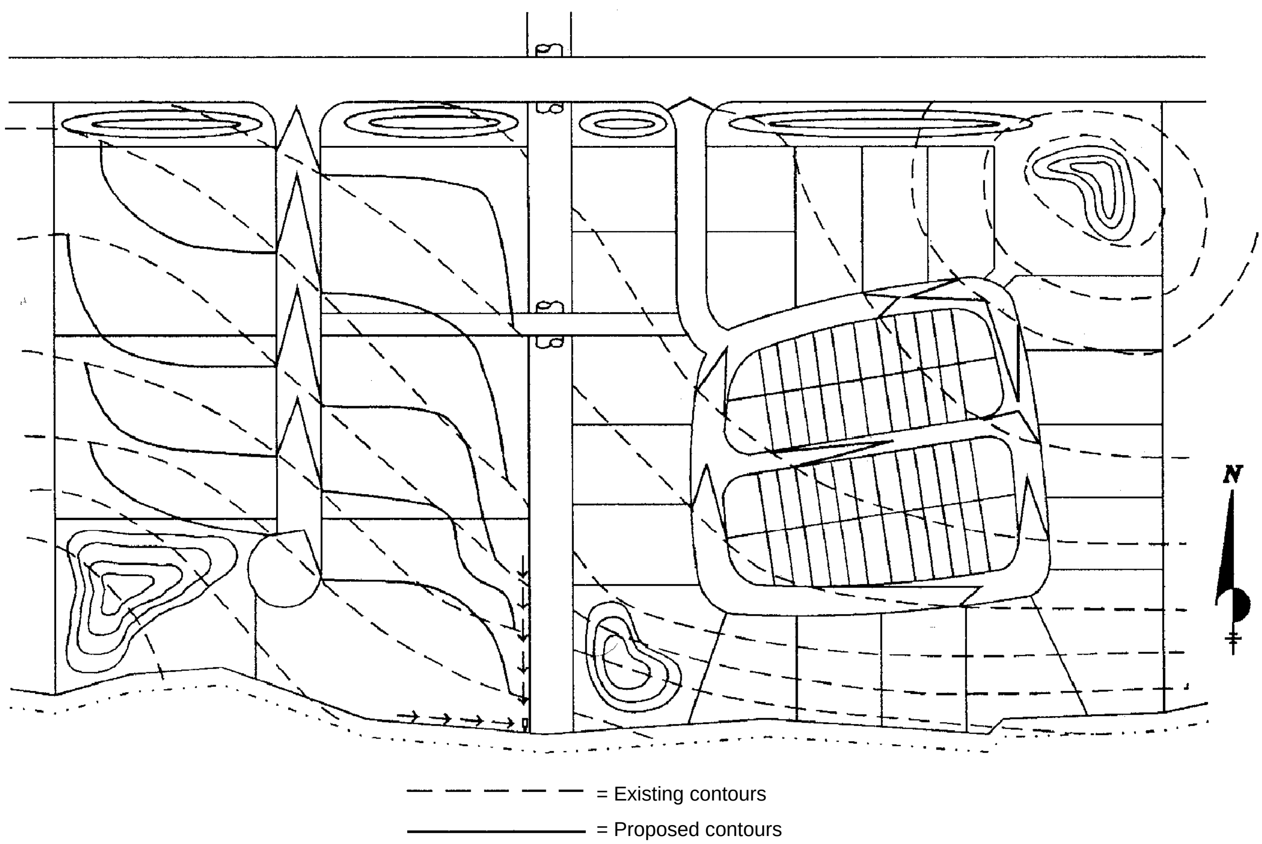


**Figure 10. Existing and proposed contours at Running Brook Estates and Business Park.**

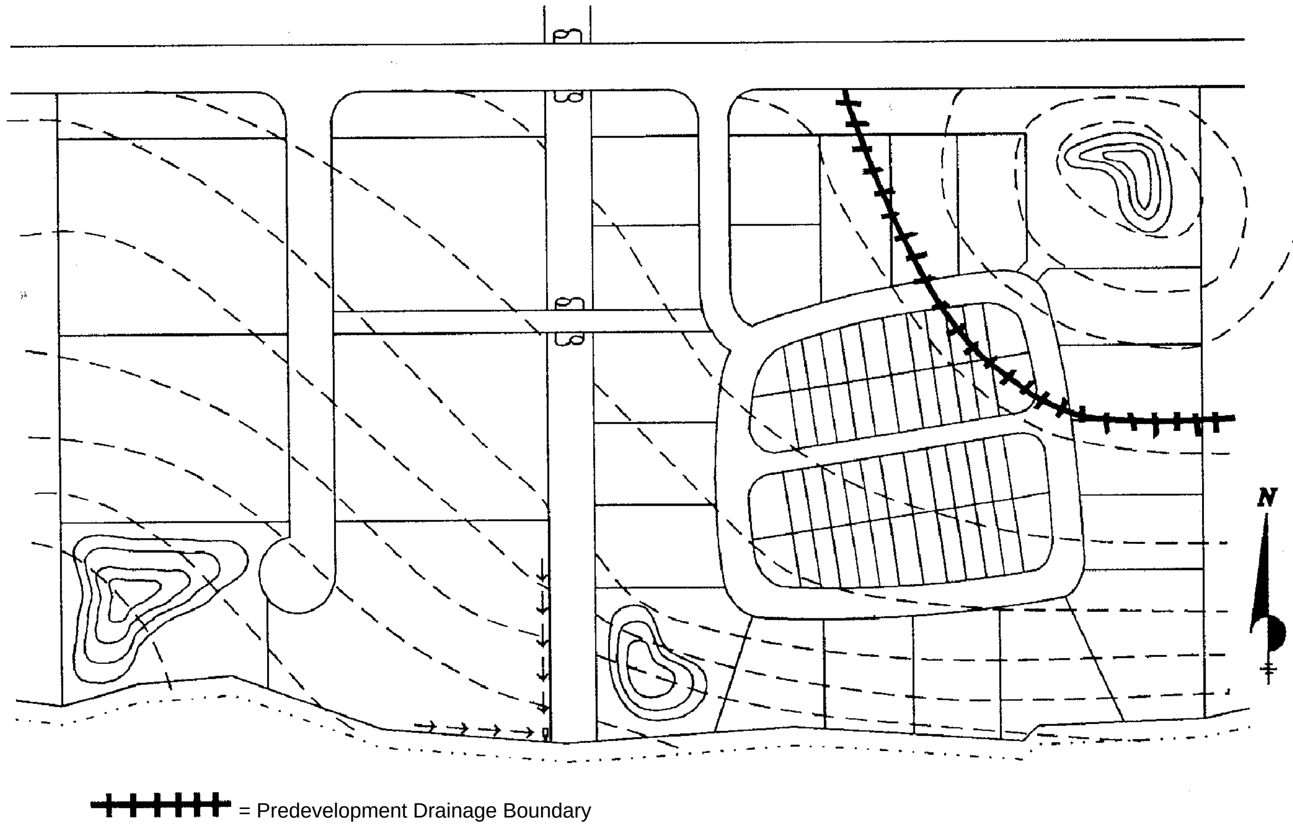


**Figure 11. Predevelopment drainage boundary at Running Brook Estates and Business Park.**

# *The Role of Landscapes in Stormwater Management*

**Steven I. Apfelbaum**
**Applied Ecological Services, Inc.,**
**Brodhead, Wisconsin**

## Abstract

This paper presents evidence that many existing streams did not have conspicuous channels and were not identified during presettlement times (prior to 1830s in the midwestern United States). Many currently identified first-, second-, and third-order streams were identified as vegetated swales, wetlands, wet prairies, and swamps in the original land survey records of the U.S. General Land Office.

The data presented show that significant increases in discharge for low, median, and high flows have occurred since settlement. Stream channels have formed inadvertently or were created to drain land for development and agricultural land uses. Currently, discharges may be 200 to 400 times greater than historical levels, based on data from 1886 to the present for the Des Plaines River in Illinois, a 620-square-mile watershed. Historic data document how this river had no measurable discharge or very low flow conditions for over 60 percent of each year during the period from 1886 to 1904.

This study suggests that land-use changes in the previous upland/prairie watershed have resulted in a change from a diffuse and slow overland flow to increased runoff, concentrated flows, and significantly reduced lag time. Preliminary modeling suggests the following results: reduced infiltration, reduced evaporation and evapotranspiration, greatly increased runoff and hydraulic volatility, and increased sediment yields and instream water quality problems caused by destabilization of streambanks.

The opportunity to emulate historical stormwater behavior by integrating upland landscape features in urban developments and agricultural lands offers stormwater management options that are easier to maintain, less expensive over time, attractive, and possibly more efficient compared with many conventional stormwater management solutions and the use of biofiltration wetlands.

## Introduction

Diverse and productive prairies, wetlands, savannas, and other ecological systems occupied hundreds of millions of acres in presettlement North America. These ecological systems have been replaced by a vast acreage of tilled and developed lands. Land-use changes have modified the capability of the upland systems and small depressional wetlands in the uplands to retain water and assimilate nutrients and other materials that now flow from the land into aquatic systems, streams, and wetlands. The historical plant communities that were dominated by deep-rooted, long-lived, and productive species have been primarily replaced by annual species (corn, soybeans, wheat) or shallow rooted nonnative species (bluegrass lawns, brome grass fields). The native vegetation was efficient at using water and nutrients, and consequently maintained very high levels of carbon fixation and primary productivity. Modern communities, in turn, are productive but primarily aboveground, in contrast to the prairie ecosystem where perhaps 70 percent of the biomass was actually created belowground in highly developed root systems. These changes in the landscape and vegetation coupled with intentional stormwater management have changed the lag time for water to remain in uplands and consequently the rate and volume of water leaving the landscape.

## The Des Plaines River

Changes that have occurred on the uplands and how these changes have affected the hydrology of wetlands and aquatic systems can be illustrated using historical and more recent data to illustrate trends in discharge of major river systems. The Des Plaines River was chosen as a study watershed because of available historical data and trackable changes in watershed land uses.

The Des Plaines River originates southeast of Burlington in southeastern Wisconsin, flows for over 90 river miles through agricultural, urban, and suburban landscape through northeastern Illinois and the Chicago region, then flows west and south, meeting with another river and becoming the Illinois River. The historical data presented are from a case before the Illinois Supreme Court and a circuit court (U.S. Department of War vs. Economy Power and Light, 1904) that dealt with the navigability of the Des Plaines River. The data were derived from a gauge station installed and operated at present-day Riverside, Illinois, from 1886 to 1904. The U.S. Geological Survey has maintained this same station since 1943. Historical data from 1886 to 1904 include a single-stage measurement per day and weekly discharge measurements (rating curves). For our studies, duration flow curves were created for the years 1886 to 1904 and 1943 to 1990. The data were compared using median values of discharge (50 percent) and also using low and high levels of discharge as indicated by the 75 percent and 10 percent values derived from the annual duration flow curves 1886 to 1904 and 1943 to 1990. The watershed area gauged at Riverside is approximately 620 square miles (400,000 acres).

In the late 1800s, about 40 percent of the watershed had been tilled and/or was developed. In contrast, approximately 70 to 80 percent of the watershed is now developed or under annually tilled agriculture land uses. Annual duration flow curve values based on linear regression analysis suggested very significant increases in discharge since 1886; perhaps 250 to 400 times (Figure 1). In 1886, the median discharge was 4 $ft^3$/sec. In contrast, in recent years the median discharge has been 700 to 800 $ft^3$/sec. Trends in low, medium, and high flow values for the Des Plaines River have undergone very significant increases.

Preliminary watershed hydrologic modeling suggests that the watershed and discharge data for 1886 to 1904 had already been modified by development and agricultural land uses; the Des Plaines River watershed was settled in the late 1830s, and thus 50 years of land use and development had passed before the 1886 data were collected. Other data resulting from the litigation suggested very clearly that the discharge of water from the Des Plaines River was significantly less between 1886 to 1904 compared with present day discharge. Because the litigation contested navigability, evidence was presented using daily stage, discharge, and water depth data on the opportunity for commercial navigation on the river. The data suggested that between 1886 and 1904, for an average 92 days per year, the river had no measurable discharge. An additional 117 days per year, the river had 60 $ft^3$/sec or less discharge, which was equal to a depth of less than 3 in. at Riverside. Based on these statistics, over 60 percent of the year the 400,000 acre watershed yielded no water or such low flows that navigation was not possible or reliable. Another 10 to 25 percent of the year the river was covered with ice.

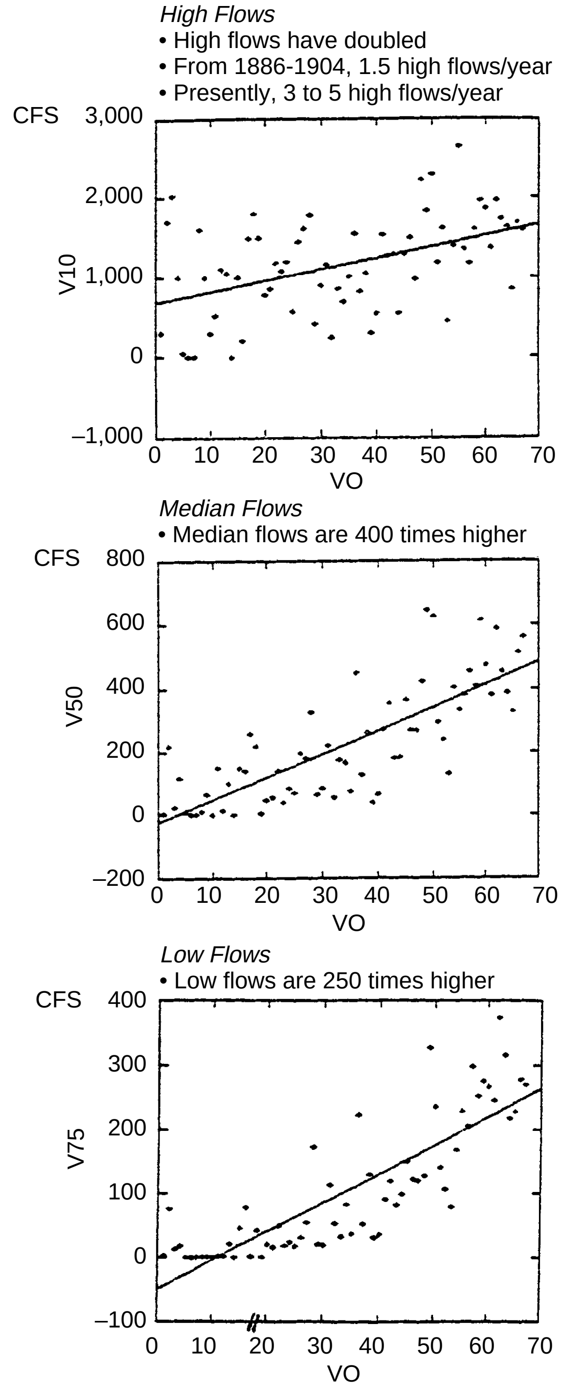


**Figure 1. Linear regression analysis and raw data plots of Des Plaines River discharge at Riverside, Illinois, 1886 to 1988. Low, median, and high flow data were derived from duration-flow curves for 75, 50, and 10 percentile annual flow levels (1).**

Additional supporting evidence of the significance of changes in the watershed and river is available. The original land survey records for parts of the Des Plaines River where section lines were surveyed identified that reaches of the river had no discernable channels. Where channels now occur, in the 1830s surveyors found wet prairies, swamps, and swales but usually no conspicuous or measurable channel widths. Channels and "pools" were identified in some locations and with greater frequency downstream in the watershed. The original land surveyors were under contract by the U.S. Government Land Office to document the vegetation types covering the land and to identify, where possible, the widths and depths of streams when they were encountered during the process of laying out the section lines.

## Conclusions and Applications of the Findings

These data suggest very clearly that highly significant changes in the hydrology, hydraulics, and water yield from the Des Plaines River watershed have occurred since settlement. Other major river and watershed systems have yielded similar results, suggesting the transferability of the concepts and general conclusions reached from the studies of the Des Plaines River. These findings and their applications are discussed below.

### *Natural Ecological System Functions and Processes Should Be Emulated*

#### Water Yield

The historical landscapes "managed" stormwater very differently than it is managed by present-day strategies. Historical data clearly indicate that a relatively small percentage of the precipitation in a watershed actually resulted in measurable runoff and water leaving the watershed. In fact, preliminary analysis suggests very strongly that an average 60 to 70 percent of the precipitation in the watershed did not leave the watershed from the Des Plaines River; this water was lost through evaporation and evapotranspiration. Analysis predicts that approximately 20 to 30 percent infiltrated and may have contributed indirectly to base flow in the streams and directly to base flow in wetlands in the watershed. During a full year, the balance of the water directly contributed to flow in the "river," where an identifiable river channel now occurs.

Present-day water management strategies involve collection, concentration, and managed release of water. These activities are generally performed in developed parcels in the lower topographic positions. Historically, a greater percentage of water was lost through evaporation and evapotranspiration from upland systems. In these situations, microdepressional storage and dispersed rather than concentrated storage occurred. Weaver (1) documented the ability of the foliage of native perennial grassland vegetation to intercept over an inch of rain with no runoff generated.

#### Sediment and Pollutant Management

Because many pollutants in stormwater require water to dislodge and translocate the suspended solids to which they are adsorbed, there is a great opportunity to emulate historical functions by using upland systems to perform biofiltration functions, increase lag time, and reduce total volume and rate of runoff.

Increased discharge and velocity of water moving through channels has been documented to greatly affect instream water quality. Perhaps as much as 70 percent of instream sediment loads come from channel and bank destabilization associated with the higher velocity waters and with solufluction and mass wasting of banks after flood waters recede (2). Stabilizing (or at least reducing) hydraulic pulsing in streams can best be accomplished by desynchronization and reduction of tributary stormwater volumes and runoff rates from uplands. This can be accomplished by integrating substantial upland perennial vegetated buffers throughout developments and agricultural land uses. Buffers are designed not only to convey water and minimize erosion (i.e., grassy waterways) but also to attenuate hydraulic pulsing, settle solids and adsorbed nutrients, and reduce and diffuse the velocity, energy, and quantity of water entering rivers, wetlands, and other lowland habitats. Using upland microdepressional storage, perhaps in the form of ephemeral wetland systems and swales in the uplands, also would emulate the historical landscape conditions and functions.

#### Applications

Several example projects of "conservation developments" are now being completed, which integrate up to 50 to 60 percent of the urban development as open space planted to perennial native prairie, wet swales, and other upland communities (as site amenities). Hybernia is a 132-acre residential development in Highland Park, Illinois, designed and constructed by Red Seal Development Corporation, Northbrook, Illinois. Empirical data from Hybernia suggest that the use of upland vegetation systems in combination with ponded areas has resulted in the rate and volume of discharge being essentially unchanged before and after development. Another project, Prairie Crossing, is a 677-acre residential project designed to offer comprehensive onsite stormwater management in uplands and created lake systems. Extensive upland prairie and wet swale systems biofilter runoff and enhance the quality and reduce the quantity of water reaching wetlands and lakes in the development.

In these types of projects, upland vegetation takes several years to fully offer stormwater management benefits. In planted prairies, surface soil structure develops a three-dimensional aspect in 3 to 5 years. The development of this structure seems to have an important role both in offering microdepressional storage and increasing the lag time for retaining water in upland systems.

Restoration and native species plantings also have provided benefits where ecological system degradation has led to increased water and sediment yields. Where ecological degradation is occurring indirectly because human activities on the landscape have reduced or eliminated major processes (such as natural wildfires), restoration can provide vegetation and stormwater management benefits. Wildfires have been all but eliminated since human settlement has occurred, especially in areas that contain forests, savanna, or oak woods. In the absence of fires in many oak woods and savannas, a dense shading develops caused by increased tree canopy and dense shrub development. Where this has occurred, a reduced ground cover and soil stabilizing vegetation grows under the low-light conditions. Consequently, highly erodible topsoils containing the seeds, roots, and tubers of the soil stabilizing vegetation and higher volumes and rates of water can run off from these degraded savanna sites. The process of savanna deterioration has been documented; restoration has used prescribed burning and other strategies (3-5). Reestablishment of ground cover vegetation is key to reducing runoff, improving water quality, and reestablishing an infiltration component in degraded, timbered systems.

### *Should Wetlands Be Used for Sediment Management, or Should This Occur on the Uplands?*

Because wetlands often provide what little wildlife habitat remains in developed landscapes, and because they are attractive to wildlife, their use for stormwater management must be carefully considered. Currently, a national movement is afoot to use created (and often natural) wetlands for stormwater management and biofiltration. Many studies of existing high-quality wetlands, however, provide little or no evidence that they historically served important biological filtration and sediment management functions. Sediment deposition was generally episodic (e.g., after wildfires), was of short duration, and yielded small sediment loads compared with loads from present-day agricultural and developed lands.

Use of wetlands for biofiltration can actually aggravate existing problems for many wetland wildlife species. For example, in the Chicago region it is not unusual to find 100 to 200 parts per million lead (and other contaminants) in tadpoles (especially in frog species with a 2-year tadpole stage, such as leopard frogs, bullfrogs, and green frogs) found in wetlands receiving highway stormwater. It is imperative to understand the potential long-term toxic effects on biological systems associated with stormwater management in wetlands and contaminant mobility.

Proposals have been made to allow the materials concentrated in biofiltration wetlands to simply be buried by each additional sediment load or to be intentionally buried by adding additional soil. Contaminant mobility through biological pathways still occurs, however, from beneath considerable sediment burial. In fact, in the Great Lakes, contamination from PCBs that are often several feet below the surface of the sediments have contributed to major increased mortality rates and major morphological problems in predacious birds such as cormorants, terns, and gulls (6, 7). The literature on wetland biofiltration inadequately addresses contaminant mobility routes through biological systems and the potential threat to the viability of biological systems. Because wetlands are so attractive to biological organisms (and, in fact, the biological organisms are often key to the successful functions of the biofiltration wetlands), it is necessary to rethink and carefully design biofiltration wetland systems in the future.

Far too often, people view the lowland environments (i.e., rivers, wetlands) as the locations for treating or physically removing problems created in the upland environments. The studies briefly described in the previous section, however, suggest that stormwater, sediment loads, and the varied contaminants may be best managed on upland systems. Although the land cost for using upland rather than lowland environments for stormwater management may be higher, the efficiency and reduction in potential contaminant problems may be greater. A landscape with many upland microdepressional storage opportunities and a large buffering capacity might offer more efficient processing than would a single biofiltration wetland at the downstream end. Each buffer or depressional wetland would need to treat a smaller volume of water and contaminants. Also, upland or dispersed stormwater treatment facilities would have significantly reduced long-term maintenance costs and represent a more sustainable approach to management of stormwater. Centralized biofiltration wetlands, on the other hand, have high maintenance requirements and potential problems that include decreases in removal efficiency for some materials in the short and long term.

### *There Are No Controlled Year-Round (and Long-Term) Studies of Removal Efficiencies Comparing Uplands and Wetlands*

The stormwater treatment literature indicates that use of wetlands and measurements of removal efficiencies have been based primarily on removal during storm events passing through the biofiltration wetlands. Year-round contaminant mass-balance data are largely unavailable. Nongrowing season studies have documented the export of materials to be significant; consequently, removal efficiencies for some materials (e.g., metals, phosphorus) are not likely to be significantly reduced from what has been documented for storm event sampling. Wetland efficiencies need to be experimentally controlled and compared with upland removal efficiencies, which also have not been studied in detail (with the exception of removals for several key elements such as phosphorus). The ability of upland (soil colloids) systems to provide reliable and long-term binding and retention for many contaminants has been demonstrated (8).

## Acknowledgments

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Assistance in these ongoing studies was provided by Dr. Luna B. Leopold, Dr. James P. Ludwig, Dr. Alan W. Haney, Mr. Robert A. Riggins, and Mr. Brett Larson and others at Applied Ecological Services, Inc. Mr. and Mrs. George Ranney and Mr. David Hoffman of Prairie Holding Corporation and Red Seal Development Corporation, respectively, allowed their conservation development projects to be presented as examples here.

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# *The U.S. Environmental Protection Agency's Advanced Identification Process*

**Sue Elston**
**U.S. Environmental Protection Agency, Region 5, Chicago, Illinois**

## Abstract

Advanced Identification (ADID) is a planning process designed to identify and help protect high-quality wetland resources. The ADID process is a joint effort between the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers, in which wetland functions and values are evaluated to determine which wetlands within an ADID study area are high quality and should be protected from future fill activities or, in some cases, which wetlands are of ecologically low value and could be considered as potential future fill sites. ADID provides the local community with information on the value of wetland areas that may be affected by their activities as well as a preliminary indication of factors that are likely to be considered during permit review of a Section 404 permit application.

Final ADID products usually consist of a technical report that includes the data gathered during the ADID study, a description of how the wetland evaluation was done, and a set of maps that identify the sites determined to be either unsuitable or suitable for filling activities. EPA works closely with other federal, state, and local agencies as well as the public throughout the ADID process. Each ADID process is designed a little differently to meet the specific wetland planning needs of the local area.

## Introduction

In an effort to provide protection to remaining wetlands, the U.S. Environmental Protection Agency (EPA), in cooperation with the U.S. Army Corps of Engineers (COE) and other federal, state, and local agencies, may identify wetlands and other waters of the United States as generally unsuitable or suitable for the discharge of dredged or fill material before receiving a Section 404 permit application. This Advanced Identification (ADID) process is authorized by the regulations pertaining to Section 404 of the Clean Water Act. During the ADID process, EPA, COE, and other federal, state, and local agencies collect information on the values of wetlands and other waters of the United States to determine which wetlands in the ADID study area are of high functional value and should be protected from future fill activities and, in some cases, which wetlands are of low functional value and could be considered as potential fill sites.

## What Is an ADID?

ADID is an advanced planning process designed to provide an additional level of protection to wetlands and other waters of the United States. The ADID process is one of the few tools currently available to EPA and other regulatory agencies that can help address resource-specific issues from a broader perspective. Typically, Section 404 permitting actions are considered on a case-by-case basis. ADID provides the opportunity to evaluate permit requests against wetland resource concerns from a watershed or regional perspective. Therefore, ADID can be used to address large geographic issues such as regional wetland loss, to provide the information needed to better evaluate cumulative loss impacts, and to provide more detailed ecological information than is typically available to regulatory decision-makers.

A planning tool, ADID is advisory not regulatory in nature. ADID provides landowners and developers with advance information, allowing them to plan with more predictability regarding the Section 404 permitting program. ADID can provide environmental groups, resource agencies, or other groups with information that can be used to guide protection or restoration efforts. ADID also can give information on local wetland loss trends. Most importantly, ADID can provide local communities with information on specific values of local wetlands that can be used to help develop local ordinances or other planning efforts designed to protect wetlands with values important to the community.

ADID projects vary in size and scope. Study areas range in size from 100 acres to 4,000 square miles and have been initiated throughout the country. Nationally, 35 ADID projects have been completed, and 36 are ongoing. The ADID process can be very resource intensive, depending on the scope of the project. From start to finish, the time to complete the ADID process can range from 6 months to several years.

Final ADID products vary from project to project. Typically, a completed ADID includes a map that identifies areas that are either unsuitable or suitable for fill, a database that contains the information used to make the ADID determination, and a technical summary document that explains how the wetland evaluations were done and what criteria were used to make the unsuitable/suitable determinations. Before ADID is completed, a joint public notice is issued by EPA and COE and a public meeting is held to solicit public comment on the products. Public comments are considered before the final ADID determinations are made. The final maps, supporting data, and technical summary document are all available to the public upon request.

In Region 5's experience, ADID is most effective where there is strong local support for such a project. ADID projects that involve local agencies can be tailored to address local needs or problems, such as flood control, water quality problems, or habitat loss. Participation of local agencies in the ADID process not only provides valuable local perspective and expertise but also the opportunity for ADID determinations to be included in local comprehensive planning efforts and wetland protection ordinances.

## Lake County ADID

EPA Region 5, in cooperation with COE and several other federal, state, and local agencies, completed an ADID project in Lake County, Illinois, in January 1993. The following is a brief overview of how the ADID process worked in Lake County.

Lake County is 460 square miles and is located in northeastern Illinois. This county has been under intensive development pressure for the last 5 to 10 years. Lake County also contains a significant proportion of the wetlands and lakes within Illinois. The majority of wetlands within Lake County are isolated or above the headwaters; therefore, many small wetland fills (less than 10 acres) were authorized under Nationwide Permit 26. EPA and COE were concerned that, cumulatively, these fills could have a significant negative effect on aquatic resources in Lake County.

Lake County was interested in supporting an ADID study because local citizens were raising many wetland development issues. The county hoped that the ADID process would provide an additional level of protection for the high-quality wetlands, as well as an opportunity for the county to work with federal agencies to resolve local wetland issues. In addition, the county was beginning to work on a stormwater and wetland protection ordinance. The county viewed the ADID process as an opportunity to work with federal and state agencies to develop an evaluation methodology for local wetlands that could be used to guide implementation of the proposed ordinance.

The Lake County ADID process was started in the fall of 1989. The first meeting included representatives from federal, state, and local agencies and public interest groups. The goals of the ADID process were explained, and the wetland functions and values to be evaluated were selected based on local needs. A technical advisory committee was formed consisting of representatives from EPA, COE, the U.S. Fish and Wildlife Service, the Soil Conservation Service, the Illinois Department of Conservation, the Lake County Forest Preserve District, the Lake County Department of Management Services, the Lake County Department of Planning, the Lake County Soil and Water Conservation District, the Lake County Stormwater Management Commission, and the Northeastern Illinois Planning Commission. The committee's task was to develop the methodologies to evaluate the selected wetland functions and values. Due to resource constraints, the committee decided to focus on identifying high-quality wetland sites only. Sites identified as being of high functional value would be considered unsuitable for filling activities.

Lake County, Illinois, contains many lakes and wetlands and is undergoing rapid urban development. Issues such as degradation of water quality, flooding problems, and habitat loss are of local concern. Based on these concerns, the committee selected the following five wetland functions to evaluate for the ADID study:

- Biological community value
- Stormwater storage value
- Shoreline/bank stabilization value
- Sediment/toxicant retention value
- Nutrient removal/transformation value

In considering evaluation methodologies, the committee immediately determined that the selected approach must be capable of dealing with a very large number of wetlands. The final evaluation methodologies developed for use in the Lake County ADID process were combinations of portions of the Wetland Evaluation Technique (WET) developed for COE (1) and the Minnesota Wetland Evaluation Methodology (2) developed by the St. Paul District of COE. Portions of these methodologies were adapted to meet the needs of the Lake County ADID process. The evaluation methodologies and the criteria used to determine which wetlands and streams were of high functional value are described in detail in the Lake County ADID final report (3).

The wetlands identified as being of high functional value were considered generally unsuitable for filling activities. A wetland was determined to be of high functional value, or unsuitable, if the site included high-quality biotic communities or if the site provided three of the four stormwater storage or water quality functions. This ADID study also identified high-quality stream corridors that are designated as being unsuitable.

The preliminary Lake County ADID designations were published in a joint public notice issued by COE and EPA. Also available for public review and comment were the evaluation methodologies used, scale maps (1 in. = 1,000 ft) showing the location of all sites of high functional value, and data sheets corresponding to each site identified as being of high functional value. A public meeting also was held to gather further public comment. After considering all the public comments, five sites were added to the list of areas of high functional value.

Approximately 24,000 acres of wetlands, lakes, and streams were identified as high functional value sites. These sites include both public and privately owned property and represent about 39 percent of the wetlands and lakes remaining in the county. The Record of Decision, final public notice, report, and finalized maps were published in January 1993.

## Results and Effectiveness

It is difficult to accurately assess how effective the Lake County ADID study was in providing an additional level of protection for wetlands. The ADID maps have been used by both developers and public entities such as the Illinois Department of Transportation during site planning. In addition, COE relies heavily on the information provided by the ADID study to guide permit decisions for ADID sites. The county, however, has not yet implemented its wetland protection ordinance. Once the county's wetland protection ordinance is in place, not only will the county provide protection for ADID sites but the ordinance will also require that a buffer area be maintained around all ADID sites.

While ADID or similar advanced planning processes are resource intensive, these types of studies can be well worth the effort if the projects are well designed and the resulting information is incorporated into local comprehensive planning efforts that will guide local land-use decisions. In addition to focusing on Section 404 issues, ADID can be tailored to provide information needed for a variety of other wetland related issues. For example, ADID can be designed to provide information that assists in the selection of wetland restoration sites. Advanced wetland planning studies also can be components of larger planning efforts (e.g., watershed protection strategies) or parts of geographic initiatives (e.g., remedial action plans and lakewide management plans).

## Summary

ADID is one of the few tools available to EPA and other regulatory agencies that can substantially address resource-specific issues from a broader ecological perspective. ADID can be used in an innovative manner to address large, geographically based issues. Within an urban setting, ADID can provide information to communities regarding the functions and values of local wetlands and can guide local protection and restoration efforts while focusing on local problems or concerns.

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# *Wisconsin Smart Program: Starkweather Creek*

**William P. Fitzpatrick**
**Wisconsin Department of Natural Resources, Madison, Wisconsin**

## Abstract

Starkweather Creek drains a 23-square-mile urban watershed in the city of Madison, Wisconsin. Urban runoff had resulted in elevated levels of biochemical oxygen demand, mercury, lead, zinc, cadmium, and oil and grease in the sediments and a severely degraded fish and macroinvertebrate habitat. Historically, the creek had received significant amounts of stormwater and industrial waste discharges. Industrial activities in the watershed had included metal fabrication, battery manufacturing, meat packing, and food processing. Starkweather is the second largest tributary and the largest source of mercury to Lake Monona, a principal recreation lake for the Madison area. Downstream transport of sediments and associated pollutants from the Starkweather watershed effects the quality of this important lake, which is under a fish advisory to anglers to restrict consumption of larger walleyes due to elevated mercury levels.

To address contamination in the creek and Lake Monona and to implement the recommendation of the local priority watershed plan, Wisconsin's Sediment Management and Remediation Techniques program selected Starkweather as a sediment remediation demonstration project. A joint U.S. Environmental Protection Agency, Wisconsin Department of Natural Resources, county, and city project was developed to 1) reduce nonpoint loading, 2) control the impacts of in-place contaminants, and 3) restore the recreational value and aquatic habitat of the creek. This $1 million program included the dredging of 17,000 $yd^3$ of contaminated sediments, construction of stormwater detention ponds, development of streambank erosion controls, and aquatic habitat restoration.

## Introduction

Starkweather Creek, located on the northeast side of Madison, Wisconsin, is the city's largest urban watershed, draining 23 square miles (Figure 1). The creek discharges to Lake Monona, a principal recreation lake located in the city of Madison. The creek and its watershed have been extensively altered as a result of urbanization. Extensive ditching, channelization, wetland draining and filling, and impervious structure development have shaped the hydrology and water quality of the creek.

Starkweather Creek has been affected by both point and nonpoint pollution over time. The creek drains a heavily industrialized portion of the city where metal fabrication, battery manufacturing, meat packing, and food processing occurred. Urban nonpoint runoff is believed to have contributed significant levels of pollutants in recent years.

Recent monitoring indicated that the creek had elevated levels of sediment oxygen demand, biochemical oxygen demand (BOD), mercury, lead, zinc, cadmium, and oil and grease in the sediments and a severely degraded fish and macroinvertebrate habitat. Concern for the levels of contaminants in the sediments of the creek extended beyond the stream channel and its habitat and also encompassed the downstream impacts of the sediments on Lake Monona.

Lake Monona has a mercury advisory on large walleye due to excessive levels of the metal in the tissues of this fish. Starkweather Creek, identified as the largest source of mercury to the lake, was targeted for remediation to restore the aquatic habitat of the creek and to protect Lake Monona.

## Wisconsin Sediment Management and Remediation Techniques Program

In response to the growing awareness of natural resources managers of the continuing impacts of in-place pollutants associated with sediment deposits in the state's waterways, the Wisconsin Department of Natural Resources (DNR) established an interdisciplinary team to develop necessary assessment and remediation tools to restore affected waters of the state. The Wisconsin Sediment Management and Remediation Techniques (SMART) Program has brought together

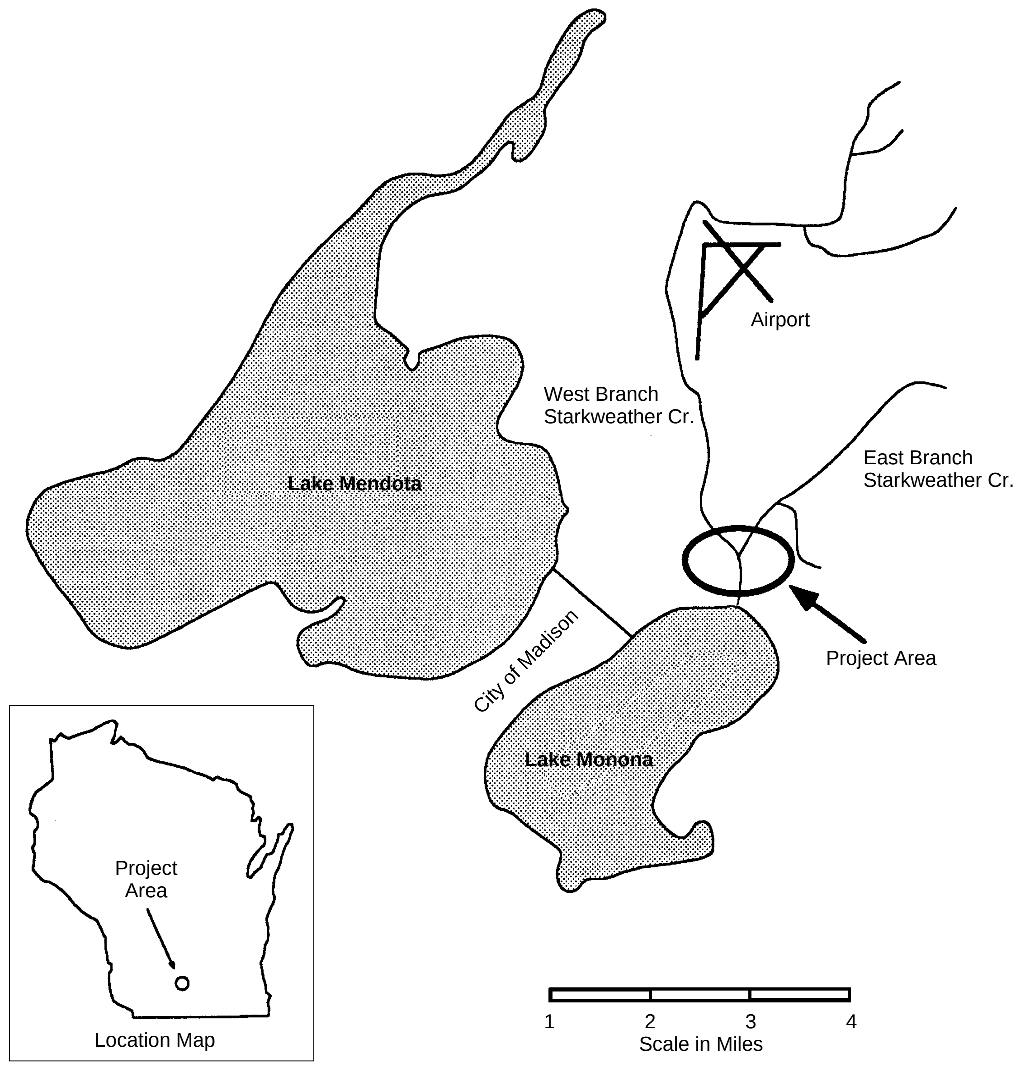


**Figure 1. Location map of Starkweather Creek and the restoration project area.**

expertise in environmental toxicology, aquatic habitat assessment, hydrographic surveying, sediment mapping, sediment engineering, and remedial technology. The SMART Program has two basic responsibilities: 1) define the extent of sediment contamination and impacts on the waters of the state and 2) guide the remediation of contaminated sediments.

The SMART Program coordinates the state's contaminated sediment activities with various universities and federal programs, such as the U.S. Environmental Protection Agency's Superfund and Great Lakes National Program Office Assessment and Remediation of Contaminated Sediment (ARCS) programs.

## Monitoring Data

Starkweather Creek, the first sediment cleanup demonstration of the Wisconsin SMART Program, provided an opportunity to use advance monitoring of the many components of an aquatic system affected by contamination in sediments. Several assessment techniques were used to define the degree of sediment contamination, stream water quality, and aquatic habitat (Table 1). Later sections of this paper address monitoring performed during dredging to assess on- and offsite impacts of the cleanup. Postremediation monitoring will continue for 2 years to document the changes and response of the creek.

## Remediation Planning

Starkweather Creek was selected as the first sediment remediation demonstration for the SMART Program based on recommendations from the state's DNR management districts, on the relative small scale of the site, and on ranking of the site with the SMART selection criteria. This criteria included:

- Impaired uses of the water body
- Adequate data for feasibility analysis
- Upstream pollution source controls
- Local support

- Adequate access
- Integration with other state and local programs

The specific project goals and objectives were developed by a project implementation team assembled from representatives of relevant state and local agencies and bureaus who guided the development of the project work plan, schedule, and budget. Individual members were responsible for ensuring that their program's relevant regulations were followed and the work plan was consistent with program policies and goals.

**Table 1. A Summary of Starkweather Creek Preremediation Monitoring Data**

| | Range | Average | Total Weight |
|---|---|---|---|
| **Sediment Chemistry** | | | |
| Mercury | <0.1–3.5 | 1.1 ppm | 40 lb |
| Lead | 33–320 | 130 ppm | 2.4 tons |
| Chromium | 9–31 | 19 ppm | 0.35 tons |
| Oil and grease | 1,500–3,600 | 2,800 ppm | 51 tons |
| PCBs | <0.14 ppm | <0.14 ppm | |
| Bulk density | 65–106 | 80 lb/ft$^3$ | 18,400 tons |
| **Water Column** | | | |
| Mercury (total) | 1.69–1.70 ng/L | | |
| Mercury (methyl) | 0.033–0.050 ng/L | | |
| Lead | <3–10 µg/L | | |
| Chromium | <3–18 µg/L | | |
| Phosphorus–P | 0.03–0.37 mg/L | | |
| DO | 3.3–14.6 mg/L (37.5–120% saturation) | | |
| COD | 10–38 mg/L | | |
| Ammonia–N | 0.04–1.8 mg/L | | |
| **Fish Tissue** | | | |
| Freshwater drum (three samples, 10–19 in.) | 0.16–0.48 ppm mercury | | |
| Carp (three samples, 18–26 in.) | 0.09–0.11 ppm mercury | | |
| **Caged Fish Bioaccumulation** | | | |
| Minnows, 2–wk exposure | 0.012–0.018 ppm mercury | | |
| Minnows, 4–wk exposure | 0.012–0.016 ppm mercury | | |
| **Toxicity Characteristic Leaching Procedure (TCLP)** | | | |
| Sediment leaching test (three samples) | <1 mg/L lead | | |
| **Sediment Mapping** | | | |
| Surveyed cross sections at 100–ft intervals | | | |
| 17,000 yd$^3$ of soft sediment measured | | | |

Following the development of the initial work plan, public informational meetings were held to solicit comments and suggestions. Presentations were also given to neighborhood associations and local environmental groups. Fact sheets outlining the proposed scope of work were distributed at these meetings. These meetings provided the implementation team with feedback on the scope and schedule of the work plan and a sense of the public's priorities regarding the restoration. Most of the public responses were requests for further clarification of the monitoring data, the permitting process, environmental safeguards during remediation, and potential exposure of local residents to contaminants in the sediments. One of the most frequent concerns for local residents was the removal of trees along the creek. The comments provided by the public and interested organizations were, where practical, incorporated into the work plan. For example, the replanting and vegetative restoration aspects of the project were developed in greater detail and the scope of the replanting was increased to address the concerns expressed at the public meetings.

Press releases and direct mailing to interested citizens and residents were used to keep the public involved and informed on the progress of the project.

## Work Plan

The Starkweather Implementation Team developed the remediation work plan to achieve the goals of reducing pollutant loading to Lake Monona, restoring the aquatic habitat and fishery, and improving recreational use and access to the creek. The work plan included the following tasks to achieve these goals:

- Dredge 17,000 yd$^3$ of contaminated sediments.
- Improve the habit for fish and aquatic life through riprapping.
- Regrade and stabilize the eroding creek banks.
- Establish shoreline buffer zones.
- Use vegetative management to improve terrestrial habitat.
- Create public access paths and fishing platforms.
- Enhance public awareness and stewardship.

Dredging was selected as the means to remove the contaminated sediments, eliminate downstream loading of these contaminants, and restore the depth and diversity of the aquatic habitat. Survey cross sections of the creek were established at 100-ft intervals through the project site and were measured for water depth and sediment thickness. These data were used to model the volume and mass of contaminated sediments to be removed from the channel. In addition to removing contaminants from the creek, the enlarged cross-sectional area of the channel would maintain a greater depth of water capable of holding more dissolved oxygen and would provide more cover and structure for aquatic life.

The dredging of the creek channel increased the average depth from 1.5 to 4 ft. The average maximum depth of the channel thalweg was increased from 2 to 7 ft. Figure 2 is a typical cross section of the creek showing the pre- and postproject channel geometry and changes in water depth and streambanks.

Hydraulic studies of the creek channel and Lake Monona were performed to assess the local and regional impacts of dredging Starkweather Creek. This work was performed to assess issues related to changes in water surface elevations, channel stability, base level lowering, and potential upstream bed erosion. Starkweather Creek throughout the project area is in the backwater of Lake Monona. The water surface elevation of the creek is the same as the downstream lake. Therefore, the deepening of the creek by dredging would not decrease the water surface elevation or promote upstream bed or bank erosion.

Riprapping was selected for shoreline protection to protect the bank soils from waves and currents and to provide structure for fish and aquatic life. Sheet pile was used in selected areas where the steepness of the shoreline required vertical protection and regrading was not feasible (e.g., near buildings, roadways, and bridges). Vertical shore protection (sheet pile) was avoided in most areas because it presents a less than natural appearance and forms a barrier to aquatic life migration from water to land.

The banks of Starkweather Creek exhibited significant undercutting and failure and were a significant source of sediment to the creek. The failure of the creek banks undermined shoreline trees and vegetation and produced a perpetuating process of landward erosion of

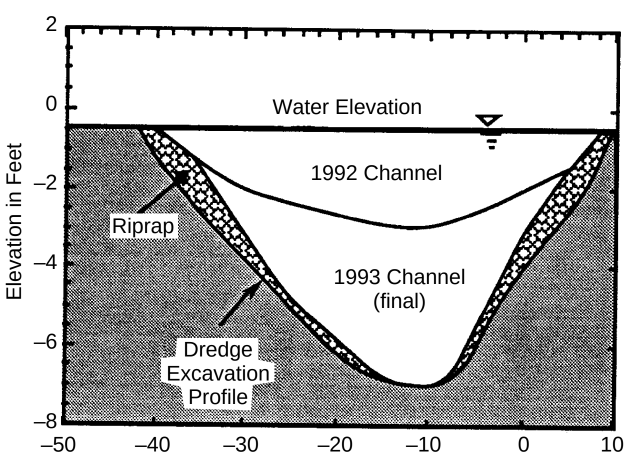


**Figure 2. Starkweather Creek example cross section showing the channel profile before and after dredging.**

increasingly steep banks. Eventually, the creek would have reached a hydraulic equilibrium by reshaping the channel geometry to a much wider and shallower channel. This process would have eliminated the fishery and small boating uses, however, and would have undermined local structures such as roadways, bridges, and buildings.

The banks of the creek were stabilized by regrading the abovewater slopes from vertical to 3:1 (horizontal:vertical), covering with protective riprap, and finally topping with a 6-in. seed bed planted to native grasses, shrubs, and trees. The near shore areas of the creek banks were planted to provide a vegetative buffer zone to filter pollutants carried by overland flows to the creek.

The terrestrial habitat along Starkweather Creek, although degraded, did provide important food and cover to insects, birds, and animals. Principal goals of the remediation project were to carefully manage all construction activities to minimize disturbances to the existing vegetation, to restore quality terrestrial areas disturbed by the creek restoration construction activities, and to improve the habitat where possible. A vegetation management and restoration plan was developed by the city's landscape architects to identify existing important tree and shrub specimens along the creek that were to be protected during construction work. The management and restoration plan was integrated with the construction plans, and close cooperation between the landscape architects, contractors, the DNR, and city engineering staff was used to resolve conflicting needs for access and mobility of the heavy equipment and the need to preserve desirable species. Trees and shrubs were initially either classified for saving or removal before construction. To reduce disturbance to the site and the costs of revegetation, the landscape architects and construction supervisors performed a final walking tour of the site to identify additional trees and shrubs, initially classified for removal, that could be saved if practical. This process provided the supervising field engineer with the discretion to either modify the construction plans and activities in the field to try to preserve existing vegetation or to permit the construction contractors to remove the specimens to facilitate access and work activities.

The project area was scheduled for replanting in the early spring of 1993. In addition to native and park grasses, 1,400 trees and shrubs were to be planted, including white ash, basswood, oak species, and maples. Planting would be located and spaced to provide optimal habitat areas along the shore of varying species, heights, and distribution.

Public access was provided to allow pedestrians to walk the site without disturbing the wildlife areas or trampling the banks of the creek. Landscape architects designed walkways to connect the project site with existing city parks and natural areas. Access to the creek was provided by low-lying shore areas and fishing/canoe access platforms constructed into higher creek banks near the water line.

Public awareness and stewardship was encouraged from the start to involve local groups throughout the project from early project design through final restoration. Regular press releases, media interviews, talks to neighborhood groups, direct mailings on project activities, aquatic education tours, fishing-for-kids clinic, and a volunteer planting event were used to keep people involved in and informed about the restoration.

## Permits and Regulatory Review

The environmental restoration of Starkweather Creek included construction activities that were under the administrative and regulatory jurisdiction of several programs and agencies. Guidance from members of the implementation team representing the state's Water Regulation and Zoning, Solid Waste, and Environmental Assessment Bureaus were incorporated in the development of the project work plan and construction plans. City personnel guided the planning for compliance with local ordinances and coordination with local utilities. Permits were necessary for dredging and shoreline excavation and filling. In addition, regulatory review and approval was requested for the management of sediments dredged from the creek. Related regulations requiring compliance were historical and archeological site assessment, floodplain zoning regulations, and state environmental assessment guidelines. The city of Madison was the applicant for the construction work. Because many portions of the creek shoreline in the work area are privately owned, the permit required that either all riparian landowners individually apply for permits or that they assign the city to act as their agent for the permit application. A form letter was sent to the riparian landowners requesting their approval for the city to apply for the permit in their behalf. All riparian landowners in the project area approved, and copies of the signoff letters were then submitted to the U.S. Army Corps of Engineers and DNR.

## Construction

Following completion of the construction plans, sealed bids were requested from qualified, interested contractors. The lowest of five bids was accepted. Speedway Sand and Gravel, Inc., of Madison, Wisconsin, was awarded the contract with a bid 17 percent lower than the highest bid.

### *Retention Site*

The sediment retention and dewatering facility, 6 miles southeast of the project area, was built in January 1992. The site covered 2.8 acres and was built on county-owned land at the local municipal landfill. The sediment retention facility was designed to dewater the sediments and contain the sediment and carriage water. The facility is square in plan view with 7-ft berms built of local clay soils. The bottom was unlined but consisted of several feet of clay. Local monitoring wells provide data on potential leachate from the facility. A concrete drop inlet spillway was built into the facility to allow excess water to be pumped to a sanitary sewer if necessary.

The retention site was built to contain 17,000 yd of sediment with a 25-percent bulking factor and to provide a minimum of 1.5 ft of freeboard to contain direct precipitation and provide a margin of safety.

Dewatered sediments from the facility are available for use as cover on the landfill.

### *Site Preparation*

A double silt curtain of geotextile fabric was placed across the creek at the downstream end of the project in mid-November 1992. The silt curtains were intended to trap debris in the streamflow generated by construction activities. In addition, the porous fabric was intended to trap sediments resuspended by the dredging. The curtains were held in place at the top by a half-inch steel cable tied to trees on the bank and weighted at the bottom by a heavy logging chain.

Utility representatives identified and marked all pipelines, cables, and utility facilities along the creek in the project area.

Site clearing and grading for heavy equipment access followed the installation of the silt curtains. Access roads and trees to be left undisturbed were clearly identified to minimize site disturbances and the cost of restoring vegetation.

### *Dredging*

Dredging began on the upstream end of the west branch of Starkweather Creek on November 19, 1992. Dredging was performed with a backhoe. Construction activities were staged through the project area such that approximately 100 yd of streambed was dredged, the banks were shaped to a stable slope, and then the site was riprapped. The goal of this sequence was to minimize the size of the project area opened by construction. In addition, because the project is in a residential neighborhood, keeping the principal work confined to a limited area at one time minimized noise and dust in the area.

Dredging, bank shaping, and stabilization proceeded in a downstream direction on the west branch to the confluence with the east branch. When the west branch was finished, work moved to the upstream end of the east branch. Approximately 12 dump trucks were used to haul the dredged sediments to the retention facility. Trucks were loaded on average every 5 minutes. To prevent leakage from the trucks, the tailgates were fitted with neoprene seals, and chain binders were used to provide a backup to the tailgate lock. No sediment spills occurred during hauling. Dredging was completed on January 27, 1993. Bank shaping and stabilization work finished 2 weeks later.

Nearly 14,000 tons of riprap and 3,400 tons of crushed stone were used on the project. Bank shaping involved 3,200 $yd^3$ of soil.

### *Dredge Monitoring*

Monitoring during dredging and other construction work was performed to track the impact of these activities on the creek and Lake Monona. Visual observations were made daily of the degree of turbidity changes caused by construction. Best management practices related to the work on site were used to minimize the instream and offsite impacts. Water sampling for chemical analyses was performed on a weekly basis at upstream reference sites, downstream of the dredging, and above and below the silt curtains. Creek water samples were analyzed for metals (arsenic, cadmium, calcium, copper, chromium, iron, lead, magnesium, nickel, zinc), nutrients (ammonia, nitrate and nitrite, total Kjeldahl nitrogen, total phosphorus), and general water quality parameters (suspended solids, chemical oxygen demand, BOD, conductivity, pH, alkalinity, hardness, temperature, dissolved oxygen).

Monitoring results indicate that there was no significant difference between the water quality parameters at the upstream reference sites and at the downstream end of the project on the dates of sampling. Figure 3 is a plot of selected water quality parameters measured on December 3, 1992, during the dredging activities. On this date, dredging was performed approximately 300 yd downstream of the upstream reference sampling site on the west branch. Sampling was also performed at the first bridge downstream of the dredging site. Other data shown in Figure 3 were obtained on the same date at a reference site on the east branch above the project and at two locations on the downstream end at the silt curtains. In can be seen in this figure that data from the dredging site show significantly higher values than at other sampling sites. The concentrations from the downstream end of the project (at the silt curtains), however, are equivalent to the undisturbed reference sites for most parameters, indicating that the resuspension of sediment and pollutants from the dredging had minimum offsite impacts. Lead and zinc values did exhibit an increase at the downstream site samples (Figure 3) compared with the upstream reference sites; however, the values at the downstream sites were within the

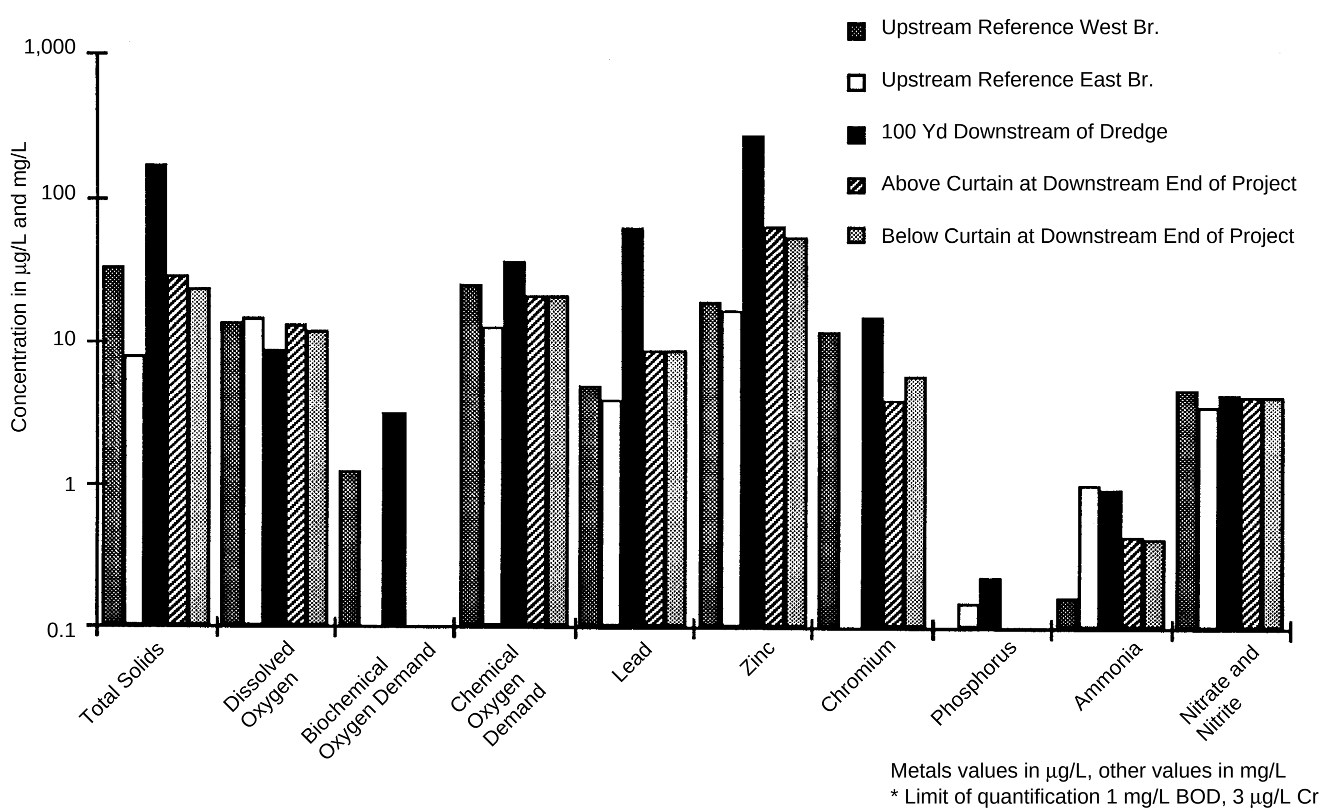


**Figure 3. Selected water quality monitoring data, Starkweather Creek, December 3, 1992.**

range of values measured over time at the undisturbed reference sites. Lead and zinc concentrations in water at the downstream end of the project were well below State Water Quality Criteria NR105 for acute and chronic toxicity in all water samples.

The silt curtains had little effect on the water quality of the stream—nearly all parameters were at the same levels above and below the curtains. Sediments and associated contaminants resuspended by the dredging work settled fairly quickly in the creek channel, and downstream loading to Lake Monona remained at background levels during the construction work. This project deployed the silt curtains normal to the streamflow (i.e., across the width of the channel) in an attempt to trap debris generated by the construction activity and to control resuspended sediments. The curtains were effective in trapping floating debris; however, they were not always effective in filtering solids from the streamflow. Figure 3 shows a slight drop in solids concentration across the silt curtain; however, the difference in concentration is fairly low and was not seen in most water sampling days. Field observations of the performance of the curtains showed that during all but the lowest base flow, the curtains would "billow out" to the downstream, allowing the streamflow to pass beneath the curtains.

## Postremediation Monitoring

Routine water quality sampling will continue on a monthly basis for a least a year following the completion of construction work. Additional monitoring intended to document the restored conditions of the creek include fish shocking surveys, caged fish bioaccumulation, sediment bioassay, sediment chemistry, qualitative habitat assessment, and macroinvertebrate sampling (sediment and artificial substrate). These additional activities will be performed over the next 2 years to assess the success or failure of the restoration work, help to refine further work at other aquatic restoration projects, and guide the development of standard procedures for sediment assessment work.

## Summary and Conclusion

Contaminated sediments can be managed to restore lost beneficial uses of a degraded waterway. The environmental restoration of Starkweather Creek has demonstrated that the knowledge and skills of various environmental programs can be successfully coordinated to accurately assess the degree of contamination, identify necessary sediment removal and disposal techniques, develop and implement a cross-program work plan, and carefully monitor the site disturbance and final restoration.

Some important aspects of this project that were critical to its successful implementation were cross-program coordination and communication, public communications and feedback, construction field supervision, and a significant investment in environmental monitoring to guide the development of the work plan and document the results of the restoration.

# *Wolf Lake Erosion Prevention*

**Roger D. Nanney**
**Soil Conservation Service, Crown Point, Indiana**

## Abstract

The U.S. Environmental Protection Agency (EPA), Region 5, in cooperation with the Lake County, Indiana, Soil and Water Conservation District, the City of Hammond, Board of Park Commissioners, and the U.S. Department of Agriculture, Soil Conservation Service, prevented bank erosion on over 300 m of the east shore of Wolf Lake. This project was funded through a $70,000 grant from EPA under Section 319(h) of the Clean Water Act. EPA had identified Wolf Lake as part of the Internal Joint Commission's Great Lakes Area of Concern, along with the Grand Calumet River Basin in northwest Indiana. Various sources of sediment were contaminating the lake, but the Park Board determined that the shoreline erosion was the highest priority. The bank was also one of the few remaining habitats of silverweed *(Potentilla anserina),* a plant on the Indiana endangered species list. A member of the rose family *(Rosaceae),* silverweed grows on wet, sandy shores in Canada south to Iowa, the Great Lakes, and coastal New England. When the Indiana Department of Natural Resources identified the plant at the site, the project was in jeopardy until a compromise was reached. Limestone riprap was chosen as the nonpoint source pollution/best management practice material to stabilize the 0.3- to 1.0-m bank. Wave action induced by wind was the cause of the bank erosion problem. Average fetch exposure, shore geometry, and shore orientation proved to be the significant factors in designing a successful shoreline protection system.

## Introduction

The southern shoreline of Lake Michigan, in northwestern Indiana, is one of the major urban and industrial centers in the Great Lakes region and includes the cities of East Chicago, Gary, Hammond, and Whiting in Lake County, Indiana (1). The heavy industry in this area contains approximately 40 percent of the steel making capacity of the United States, and one of the largest petrochemical complexes in this country. This combination has created one of the most environmentally degraded areas within the entire Great Lakes basin.

Wolf Lake is located in the northwest corner of the region and is an important remnant of what once was a large Lake Michigan bay. As the Great Lakes' levels dropped from the Nipissing through the Algona to the present-day Lake Michigan, several coastal area lakes developed (2). Among these lakes were Calumet, Hyde, Wolf, Berry, and George. Today, only Calumet, Wolf, and small remnants of Lake George remain; the others were drained and filled to allow for development (3).

The present surface area of the lake is 156 ha in Indiana and 170 ha in Illinois. As would be expected because it was once a shallow bay, Wolf Lake is shallow, with a mean depth of only 1.5 m. The maximum depth is listed as 5.5 m in areas influenced by past sand mining (1). Wolf Lake is not protected by natural features such as hills or stands of trees. Therefore, strong winds frequently cause wave action to pound the eastern shoreline and create erosion and sediment.

## Shoreline Erosion and Protection

Few things are a bigger eyesore and problem for lakeshore users than an eroding shoreline. A variety of lake shoreline protection practices are designed to stabilize and protect these areas against the forces of erosion, such as scour and erosion from wave action, ice action, seepage, and runoff from upland areas. These practices are both nonstructural (vegetation or beach sloping) and structural (flexible structures such as riprap and rigid structures such as seawalls).

Shoreline erosion is a significant problem in several areas along Wolf Lake's shoreline. The problem has been documented by historical photographs and personal accounts, but estimating the volume of shoreline eroded is difficult. Photographs indicate that the eastern shore has receded 15 m. Photographs from 1938, when compared with recent photographs, show that the area has receded at a rate of about 0.3 m/yr.

The lake's shallow water depth, long wind fetch, and motor boat use all contribute to the waves eroding the shoreline. The scarcity of rooted littoral vegetation and the sand, slag, and gravel texture of the scoured littoral sediment are further evidence of wave action. Fetch is defined as the distance a wind blows unobstructed over water, especially as a factor affecting the buildup of waves. The average fetch exposure, shore geometry, and shore orientation are significant factors in successful shoreline stabilization (4).

Vegetation effectively controls runoff erosion on slopes or banks leading down to the water's edge; however, vegetation is ineffective against direct wave action or seepage-caused bank slumping (5). Diverse, moderately dense stands of aquatic plants are desirable in a lake's littoral zone. Emergent aquatic plant communities protect the shoreline from erosion by damping the force of waves and stabilizing shoreline soils (6).

Riprap armoring is a flexible structure constructed of stone and gravel that is designed to protect steep shorelines from wave action, ice action, and slumping due to seepage. The riprap is flexible in that it will move slightly under certain conditions. This improves its ability to dissipate wave energy.

Seawalls, bulkheads, and retaining walls are rigid structures used where steep banks prohibit the sloping forms of protection. Seawalls do not primarily dissipate wave energy but rather redirect the wave energy away from the shore (7).

## Site Evaluation

The Hammond Park Board had been in contact with the U.S. Environmental Protection Agency's (EPA's) Region 5 office in Chicago, Illinois, about an ongoing erosion problem at Wolf Lake in Hammond, Indiana. The site was actively eroding and endangering the east shoreline for 300 m. This was part of the Internal Joint Commission's Area of Concern and was identified in the area Remedial Action Plan (RAP) by the Indiana Department of Environmental Management (IDEM). The Park Board called on EPA for technical and financial assistance, and project development began.

In the fall of 1990, the eastern shoreline of Wolf Lake was surveyed by the Soil Conservation Service (SCS). The survey revealed a water depth ranging from 0.3 to 1.0 m, with a vertical dropoff. This area had been eroding for an undetermined amount of time and had reached a point where it would soon undercut a pedestrian trail connecting a picnic area with the beach. Over the years, the Park Board had allowed large pieces of broken concrete to be dumped along the shoreline to try to control the erosion. This had slowed the erosion process in some areas but accelerated it in others. Where the wave action could get between the concrete, the erosion continued to advance.

The undercutting of a fishing pier at the south end of the area demonstrated the strength of the wave action on the site. Although the average fetch at the site is about 1,000 m, the wave energy is funneled to the northeast and southeast shoreline by a manmade island located 200 m offshore. The maximum depth of the bay area created by this erosion is only 3 m, with the majority at no more than 1.5 m.

SCS recommended that the 300-m shoreline be stabilized with riprap. In the winter of 1990, the Lake County Soil and Water Conservation District applied to EPA for a Section 319 grant of $70,000 to stabilize the shoreline. SCS completed the designs, and the Park Board sought permit applications from IDEM, the Indiana Department of Natural Resources (IDNR), and the Army Corps of Engineers (COE). Several coordination meetings were held with the Park Board to keep them informed of the progress of the various activities. The Park Board approved the final plans in the spring of 1991, and permits were approved that summer.

During the permit review process, an IDNR biologist identified the presence of silverweed (Potentilla anserina) at the site. Silverweed, which is on the IDNR endangered species list, was growing in patches along the eastern shoreline. Silverweed is a prostrate species that sends up yellow flowers with leaves on a separate stalk. The leaves are strikingly silver beneath, divided into 7 to 25 paired, sharp-toothed leaflets that increase in size upward. The total plant length ranges from 0.3 to 1.0 m, and it flowers in June through August (8). This plant was also in danger of losing its habitat as the shoreline eroded back. The IDNR approved of the riprap project with the stipulation that care be taken to avoid main clusters of the plant.

## Riprap Size and Placement

A stone revetment, riprap involves more than simply dumping rocks on the shoreline. The SCS area-office engineer developed a design, which was reviewed by the SCS state engineer. This design included the investigation of the average depth of the bay water, wave height, depth of dropoff, and the orientation of critical winds.

The largest wave that can reach shore is 0.8 times the depth of the water (9). This would generate a wave height of 1.2 m where the water depth is 1.5 m. A maximum wave height of 0.5 m would be reached for a 1,000-m fetch over 6-m deep water with a 16 m/sec wind speed (9). Therefore, NAS No. R-5 (46 cm maximum, D50 23 cm, minimum 13 cm) graded riprap was chosen for the armor stone (9). For the bedding or filter stone, NAS No. FS-2 (5 cm maximum, average No. 4, No. 100 minimum) would be used.

With the existing concrete in place, it was difficult to determine the amount of riprap needed. An estimate was made based on an average riprap thickness of 0.6 m and enough bedding stone to fill in the voids on a typical cross section 300 m long. The plans called for a 2:1 slope for the finished riprap, which meant 800 metric tons of bedding stone and 615 metric tons of riprap was needed.

The Park Board received bids for the work and awarded the contract in the late summer of 1992. The cost for actual purchase and placement of material was $133.00 per linear meter. Additional costs associated with the project were for design, administration, and construction supervision. The construction of the 300-m barrier took 7 working days, including hauling the stone from a quarry within 16 km. Stone was placed using a large hydraulic backhoe and a front-end loader.

Chapters 16 and 17 of the SCS *National Engineering Field Manual* (10) contain detailed discussions on the selection and placement of riprap for erosion control.

## Discussion and Conclusion

The nonpoint source/best management practice (BMP) of limestone riprap was selected for the Wolf Lake project. Selection was based on the need for the practice to withstand wave energy, be cost effective, and be compatible with the endangered species plant found at the site. Revegetation was not selected as the BMP because the site was unstable and few plants could stand up to the wave action. The erosive force of wave action limits plants survival in open lakes. Aquatic macrophytes may not grow in areas where wind fetch exceeds 850 m (11). A seawall or other rigid BMPs were not selected because of their higher cost and the disturbance to the site that would be required for their installation. Another alternative not discussed here, because of the major site disturbance it would require, is regrading of the bank to a stable slope.

The design characteristics of the site taken into consideration were fetch exposure, shore geometry, and shore orientation. In addition, the resistance of dumped stone to displacement by waves depends on:

- Weight, size, shape, and composition of the stone.
- Gradation of the stone.
- Height of the wave.
- Steepness and stability of the protected area.
- Stability and effectiveness of the filter or bedding material (12).

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# *Incorporating Ecological Concepts and Biological Criteria in the Assessment and Management of Urban Nonpoint Source Pollution*

**Chris O. Yoder**
**Ohio Environmental Protection Agency, Division of Surface Water, Ecological Assessment Section, Columbus, Ohio**

## Abstract

The health and well-being of the aquatic biota in surface waters are important barometers of how effectively we are achieving the goals of the Clean Water Act (CWA); namely, the maintenance and restoration of biological integrity and the basic intent of water quality standards. Yet, these tangible products of the CWA regulatory and water quality planning and management efforts are frequently not linked nor equated with the more popularized notion of chemical-physical water quality criteria and other surrogate indicators and endpoints. Simply stated, biological integrity is the *combined* result of chemical, physical, and biological processes. Nowhere in water quality management and assessment is the interaction of these three factors more apparent than with nonpoint sources. Management efforts that rely solely on comparatively simple chemical-physical water quality criteria surrogates frequently do not result in the full restoration of ecological integrity. Therefore, ecological concepts, criteria, and assessment tools must be incorporated into the prioritization and evaluation of nonpoint source pollution abatement efforts.

## Introduction

The monitoring of surface waters and evaluation of the biological integrity goal of the Clean Water Act (CWA) have historically been predominated by nonbiological measures such as chemical-physical water quality (1). While this approach may have fostered an impression of empirical validity and legal defensibility, it has not sufficiently measured the ecological health and well-being of aquatic resources. An illustration of this point was demonstrated in a comparison of the abilities of chemical water quality criteria and biological criteria to detect aquatic life impairment based on ambient monitoring in Ohio. Out of 645 water-body segments analyzed, biological impairment was evident in 49.8 percent of the cases where no impairments of chemical water quality criteria were observed (2). While this discrepancy may at first seem remarkable, the reasons for it are many and complex. Biological communities respond to and integrate a wide variety of chemical, physical, and biological factors in the environment whether they are of natural or anthropogenic origin. Simply stated, controlling chemical water quality criteria alone does not ensure the ecological integrity of water resources (1).

The health and well-being of surface water resources are the *combined* result of chemical, physical, and biological processes (Figure 1). To be truly successful in meeting these goals, monitoring and assessment tools are needed that measure both the interacting processes and the integrated result of these processes (3). This is especially true for nonpoint sources because many of the effects involve the interactions of these factors. Biological criteria offer a way to measure the end result of nonpoint source management efforts and successfully accomplish the protection of surface water resources. Biological communities respond to environmental impacts that chemical-physical water quality criteria alone cannot adequately discriminate or even detect. Habitat degradation and sedimentation are two prevalent impacts of nonpoint source origin that simply cannot be measured by chemical-physical criteria alone. As illustrated by Figure 1, the combination of chemical and physical factors results in surface water use impairments from nonpoint sources.

The Ohio Environmental Protection Agency (EPA) recently adopted biological criteria in its water quality standards (WQS) regulations. These criteria are based on measurable endpoints regarding the health and well-being of aquatic communities. They are further structured into the state's WQS regulations within a system of tiered aquatic life uses from which numerical biological criteria are derived using a regional reference site approach (4-7). These numerical expressions of biological goal attainment criteria are essentially the end

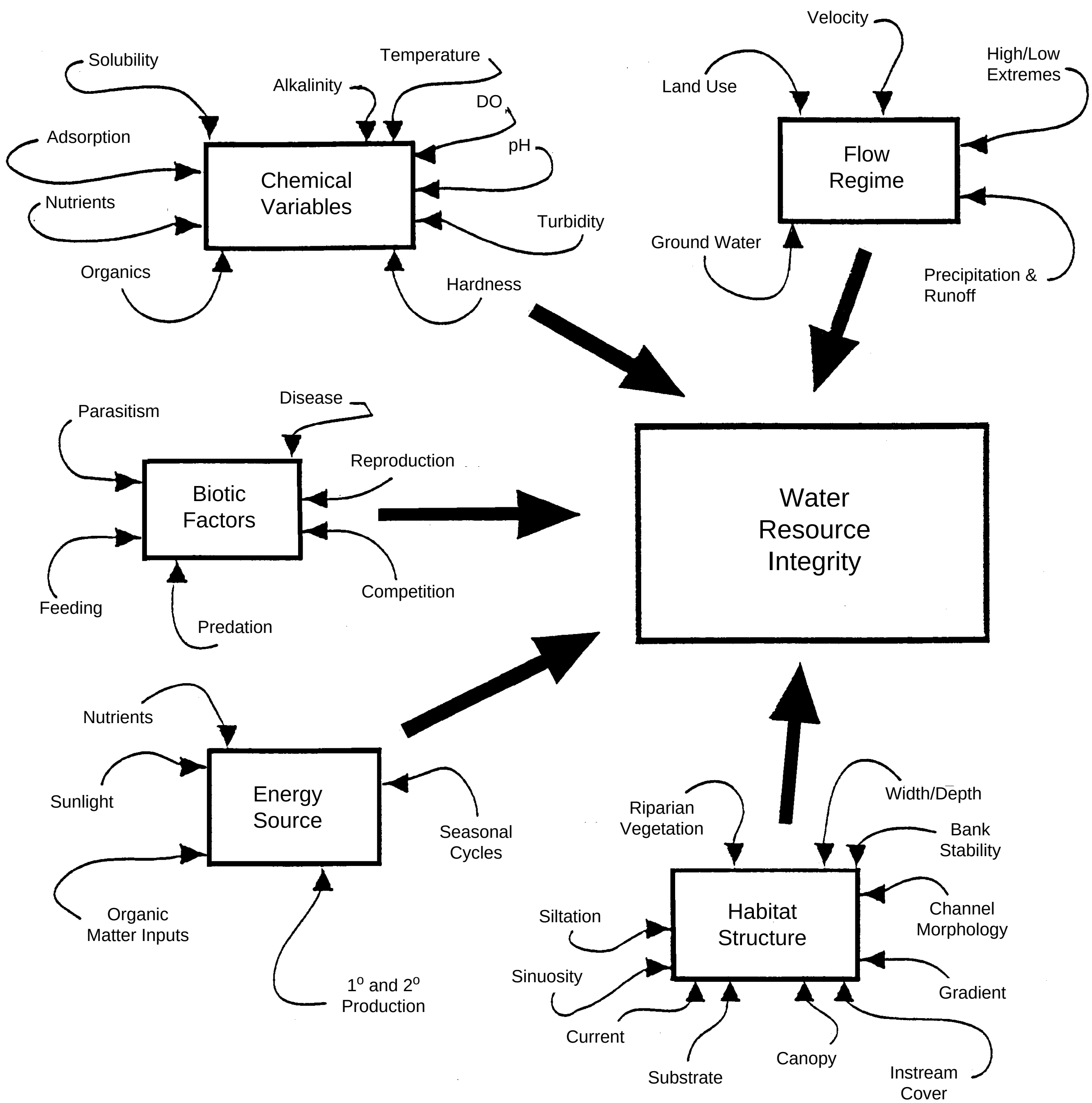



**Figure 1. The five principal factors, with some of their important chemical, physical, and biological components, that influence and determine the integrity of surface water resources (modified from Karr et al. [1]).**

product of an ecologically complex but structured derivation process. While numerical biological indices have been criticized for potentially oversimplifying complex ecological processes (8), distillation of such information to readily comprehendible expressions is both practical and necessary. The advent of new-generation evaluation mechanisms, such as the Index of Biotic Integrity (IBI) (1, 9, 10), the Index of Well-Being (Iwb) (11, 12), the Invertebrate Community Index (ICI) (5), and similar efforts (13-16), has filled important practical and theoretical gaps not always fulfilled by previously available single-dimension indices. Multimetric evaluation mechanisms, such as the IBI, extract ecologically relevant information from complex biological community data while preserving the opportunity to analyze such data on a multivariate basis. The problem of biological data variability is also addressed within this system. Variability is controlled by specifying standardized methods and procedures (17) that are then compressed through the application of multimetric evaluation mechanisms (e.g., IBI, ICI) and stratified by accounting for regional and physical variability and potential (e.g., ecoregions, tiered aquatic life uses). The results are evaluation mechanisms, such as the IBI and ICI, that have acceptably low replicate variability (18-20).

## Ecoregional Biocriteria and Determination of Use Attainment

Biological criteria can play an especially important role in nonpoint source assessment and management because they directly represent an important environmental goal and regulatory endpoint (i.e., the biological integrity goal of the CWA). Numerous studies have documented this capability. Gammon et al. (21) documented a "gradient" of compositional and functional shifts in the fish and macroinvertebrate communities of small agricultural watersheds in central Indiana. Community responses ranged from an increase in biomass with mild enrichment to complete shifts in community function. Impacts from animal feedlots had the most pronounced effects. In the latter case, the condition of the immediate riparian zone was correlated with the degree of impairment.

Later work by Gammon et al. (22) suggests that nonpoint sources are impeding any further biological improvements observed in larger rivers due primarily to reduced point source impacts. This is similar to observations that Ohio EPA has made in the Scioto River downstream from Columbus. Urban nonpoint source impacts are well known and have also been documented by numerous investigators. Klein (23) documented a relationship between increasing urbanization and biological impairment, noting that the latter does not become severe until urbanization reaches 30 percent of the watershed area. Steedman (24) used a modification of the IBI to demonstrate the influence of urban land use and riparian zone integrity in Lake Ontario tributaries. Steedman developed a model relationship between the IBI and these two environmental factors.

Biological monitoring of nonpoint source impacts and pollution abatement efforts conducted in concert with the use of more traditional assessment tools (e.g., chemical-physical) can produce the type of evaluation needed to determine where nonpoint source management efforts should be focused, what some of the management goals should be, and what determines the eventual success (i.e., end result) of such efforts. At the same time, a well-conceived monitoring program can yield multipurpose information that can be applied to similar situations without the need to perform site-specific monitoring everywhere. This is best accomplished when a landscape-partitioning framework, such as ecoregions (25) and the subcomponents, is used as an initial step in accounting for natural landscape variability. Because of landscape variability, uniform and overly simplified approaches to nonpoint source management often fail to produce the desired results (26).

Biological criteria in Ohio are based on two principal organism groups: fish and macroinvertebrates. Numerical biological criteria for rivers and streams were derived from the results of sampling conducted at more than 350 reference sites that typify the "least impacted" condition within each ecoregion (5, 6). This information was used within the existing framework of tiered aquatic life uses in the Ohio WQS regulations to establish attainable, baseline biological community performance expectations on a regional basis. Biological criteria vary by ecoregion, aquatic life-use designation, site type, and biological index. The resulting criteria for two of the "fishable, swimmable" uses, Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH), are shown in Figure 2.

Procedures for determining the use attainment status of Ohio's lotic surface waters were also developed (5, 27). Using the numerical biocriteria as defined by the Ohio WQS regulations, use attainment status is determined as follows:

- *Full:* Use attainment is considered full if all of the applicable numeric indices exhibit attainment of the respective biological criteria; this means that the aquatic-life goals of the Ohio WQS regulations are being attained.
- *Partial:* At least one organism group exhibits nonattainment of the numeric biocriteria, but no lower than a narrative rating of "fair," and the other group exhibits attainment.
- *Non:* Neither organism group exhibits attainment of the ecoregional biocriteria, or one organism group reflects a narrative rating of "poor" or "very poor," even if the other group exhibits attainment.

Following these rules, a use attainment table is constructed on a longitudinal mainstem or watershed basis. Information included in the table includes sampling location (river mile index), biological index scores, the Qualitative Habitat Evaluation Index (QHEI) score, attainment status, and comments about important site-specific factors such as proximity to pollution sources. An example of how to construct a use attainment table is provided in Table 1.

## Aquatic Ecosystems at Risk

Ecosystems that possess or reflect integrity (as envisioned by the biological integrity goal of the CWA) are characterized by the following attributes (1):

- The inherent potential of the system is realized.

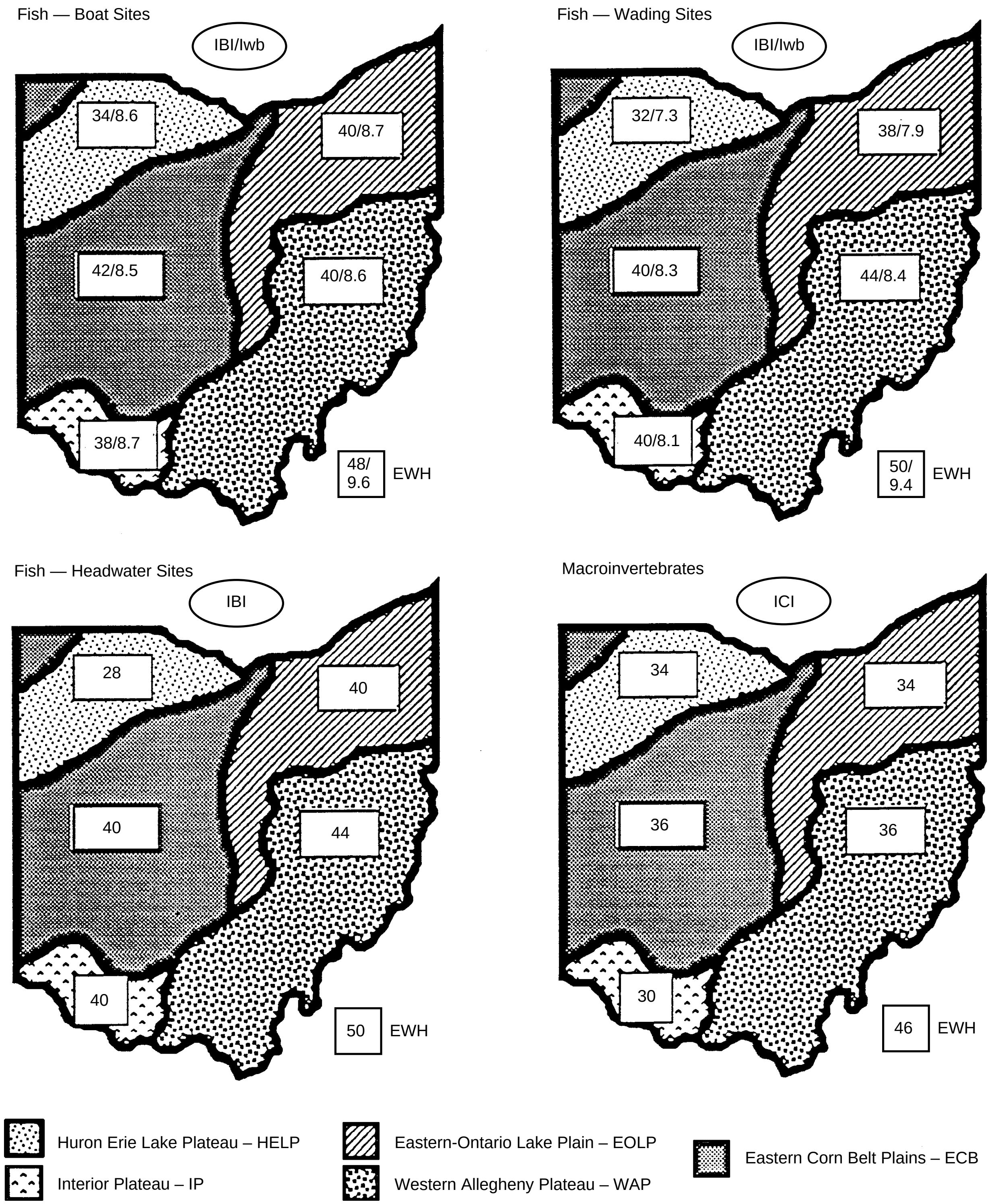



**Figure 2. Biological criteria in the Ohio WQS for the Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH) use designations arranged by biological index, site type for fish, and ecoregion. The EWH criteria for each index and site type is located in the boxes located outside of each map.**

- The system and its components are stable.
- The system retains a capacity for self-repair when perturbed or injured.
- Minimal or no external support for community maintenance is required.

Thus, ecosystems that are impaired and therefore lack integrity have had their capacity to withstand and rapidly recover from perturbations exceeded. Impaired ecosystems are likely to become even further degraded due to incremental increases in stress.

Many rivers and streams nationwide fail to exhibit the characteristics of healthy ecosystems. Recent estimates indicate that as many as 98 percent of lotic ecosystems are degraded to a detectable degree (29). Karr et al. (30) illustrated the extent to which the Illinois and Maumee River basin fish communities have declined during the past 50 years: two-thirds of the original fauna were lost from the former and more than 40 percent from the latter. Losses of naiad mollusks and crayfish have been even greater. In Ohio, long-term declines in fish communities have been extensively documented by Trautman (31). More recent information indicates that the fraction of the fish fauna that is imperiled or declining has increased from 30 to 40 percent since 1980 (32). This information indicates that lotic ecosystems are threatened in both Ohio and nationwide, an indication that existing frameworks for water resource protection and management have been essentially ineffective in preventing large-scale losses of ecological integrity. This is particularly true for ecosystems affected by habitat degradation, riparian encroachment, excess sedimentation, organic enrichment, and nutrient enrichment. All or most of these forms of degradation are evident in areas affected by urban nonpoint sources.

## Urban Nonpoint Source Pollution in Ohio

Urban watersheds in Ohio have exhibited a familiar and well-known legacy of aquatic resource degradation. Few, if any, functionally healthy watersheds exist in the older, heavily urbanized parts of the Midwest. Good quantitative estimates of the proportion of surface waters that are degraded by urbanization are lacking, however, particularly for headwater streams. It is also widely perceived that the restoration of beneficial aquatic life uses in most heavily urbanized areas is not practically attainable. This in itself presents a barrier to any notion of attaining existing use designations or upgrading use designations for waters classified for less than fishable and swimmable uses. The assignment of appropriate aquatic life and recreational uses is a challenge that Ohio EPA has dealt with over the past 15 years.

Urban and suburban development activities that have the greatest impacts on aquatic life in Ohio include the wholesale modification of watershed hydrology, riparian vegetation degradation and removal, direct instream habitat degradation via channelization, construction and other drainage enhancement activities, sedimentation and siltation caused by stream-bank erosion (which is strongly linked to riparian encroachment), and contributions of chemical pollutants. Statewide, urban and suburban sources are responsible for impairment (major and moderate magnitude sources) in more than 927 miles of streams and rivers and more than 23,000 acres of lakes, ponds, and reservoirs (32). These activities also threaten existing use attainment in nearly 160 miles of streams and rivers and may be a potential problem in more than 4,380 miles of streams and rivers that have not yet been fully monitored and evaluated (33).

While much attention is generally given to toxic substances in urban nonpoint source runoff, evidence suggests that nontoxic effects are more widespread, at least in Ohio and the Midwest. The second leading cause of impairment identified by the 1992 Ohio Water Resource Inventory, sedimentation (or siltation) resulting from urban and other land-use activities is the most pervasive single cause of impairment from nonpoint sources in Ohio. Sedimentation is responsible for more impairment (over 1,400 miles of stream and rivers and 23,000 acres of lakes, ponds, and reservoirs) than any other cause except organic enrichment/dissolved oxygen, with which it is closely allied in urban and agricultural areas. Since Ohio conducted the Ohio Water Resource Inventory in 1988 (34), this cause category has surpassed ammonia and heavy metals in rank. If the statewide monitoring database were distributed more equally across the state, sedimentation would likely be found to be the leading cause of impairment.

Although sediment deposition in both lotic and lentic environments is a natural process, it becomes a problem when the capability of the ecosystem to “assimilate” any excess delivery is exceeded. Sediment deposited in streams and rivers comes primarily from stream bank erosion and in runoff from upland erosion. The effects are much more severe in streams and rivers with degraded riparian zones and low gradient. Given similar rates of erosion, the effects of sedimentation are much worse in channel-modified and riparian zone-degraded streams than in more natural, intact habitats. In channel-modified streams, incoming silt and sediment remain within and continue to degrade the stream channel, instead of being deposited in the immediate riparian “floodplain” during high flow periods (35). This also adds to and increases the sediment bedload that continues to affect the substrates long after the runoff events have ceased.

One of the more prevalent results is substrate embeddedness, which occurs when an excess of fine materials, particularly clayey silts and fine sand, fills the otherwise open interstitial spaces between larger substrates (Figure 3). In extreme cases, the coarser substrates may be “smothered”; in other cases, the substrate can be cemented together, or “armor plated.” In either event, the principal ecological consequence is the loss of available benthic surface area for aquatic organisms (particularly macroinvertebrates) and as a location for the development of fish eggs and larvae. The soft substrates afforded by the increased accumulation of fine materials also provide an excellent habitat for the growth of undesirable algae. Thus, to successfully abate the adverse impacts of sediment, we need to be as concerned with what each event leaves behind as

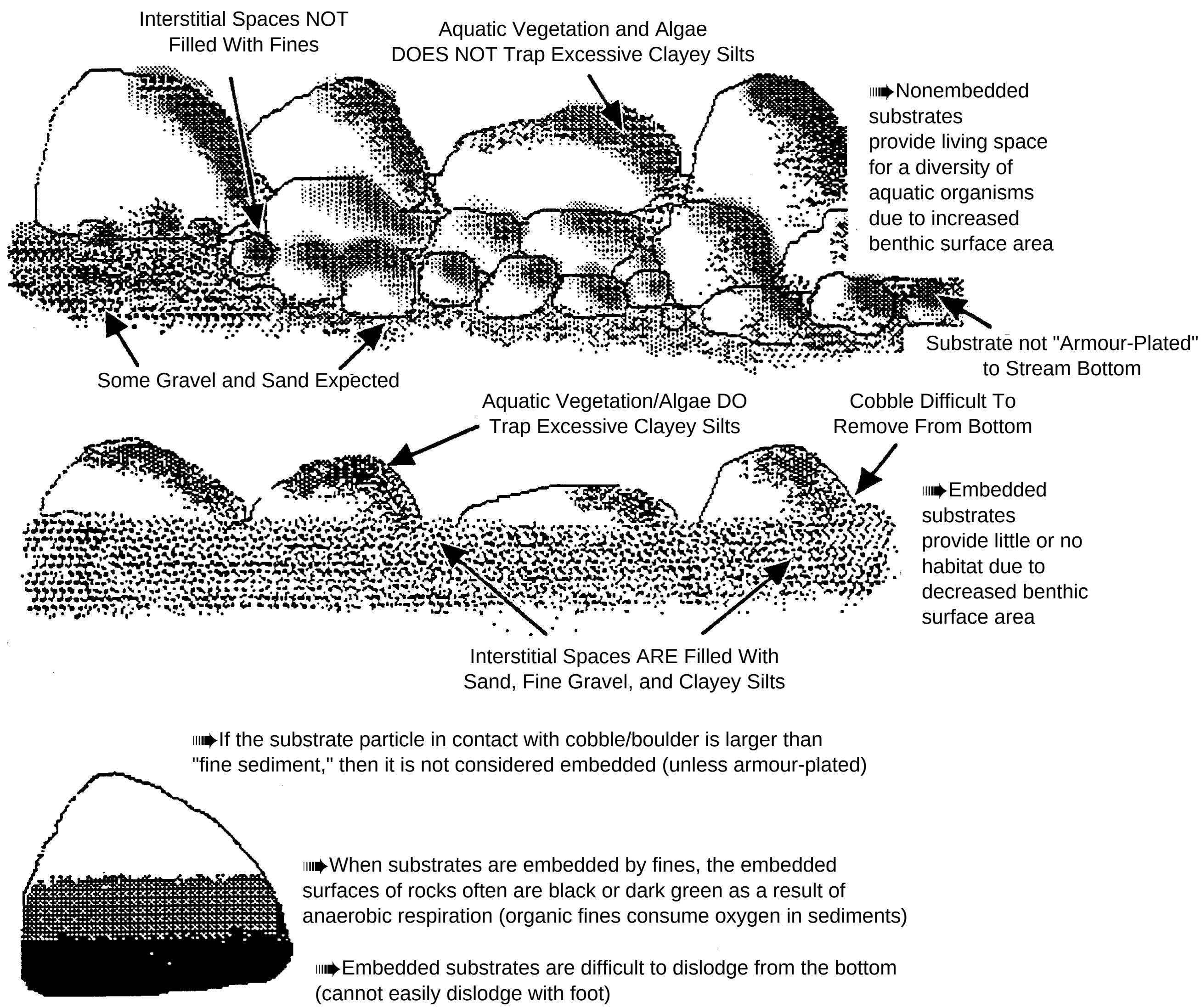



**Figure 3. Characterization of substrate embeddedness with some of the key structural signatures and a summary of some of the ecological impacts of this form of stream substrate degradation.**

much as with what takes place in the water column during each event.

The effects of sedimentation on aquatic life are the most severe in the ecoregions of Ohio where:

- Erosion and runoff are moderate to high.
- Clayey silts that attach to and fill the interstices between coarse substrates are predominant.
- Streams and rivers lack the ability to expel sediments from the low-flow channel, which results in a longer retention time and greater deposition of silt in the most critical habitats.

Estimates of gross erosion alone do not always correlate with adverse impacts to aquatic communities, although this is a frequently cited criterion for prioritizing nonpoint source management efforts. Some of the areas of Ohio that have the highest rates of gross erosion (e.g., East Corn Belt Plain, Interior Plateau, and Western Allegheny Plateau ecoregions) also have some of the most diverse and functionally healthy assemblages of aquatic life at the least affected reference and other sites (32). Many of the streams in these ecoregions have relatively intact riparian and instream habitat and thus are “buffered” against the naturally erosive conditions. The detrimental effects of sedimentation seem to be the worst in areas of the state where the proportion of clayey silts are highest, stream gradient is the lowest, and riparian encroachment and modification are extensive (i.e., Huron/Erie Lake Plain and portions of the East Corn Belt Plain and Erie/Ontario Lake Plain ecoregions).

The interaction between nonpoint source runoff and riparian and instream habitat must be appreciated and understood if impacts such as sedimentation are to be effectively dealt with. Figure 4 illustrates the interdependency of the rate of runoff, increased sediment delivery, in-channel habitat degradation, riparian zone condition, and substrate condition. An effect involving any one

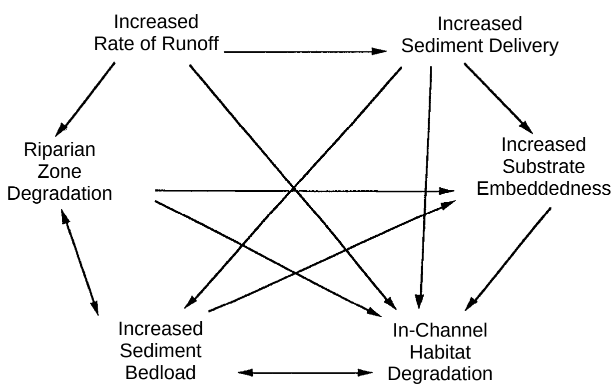



**Figure 4. Illustration of the complex interaction of nonpoint source caused changes in hydrology and sediment delivery and how each singly and in combination can degrade instream and riparian habitat.**

factor can set off a chain of events that results in cumulative changes reflected by most or even all of the interdependent factors. Two factors that are influenced in the conversion of watersheds by urban development are an increased rate of runoff and increased sediment delivery. These two factors then combine to influence other important aspects of stream habitat, such as riparian zone integrity and increased substrate embeddedness. In effect, a change in one of these factors can result in a cascading chain of events that eventually cause aquatic life use impairment or inhibit the ability of a degraded stream to be successfully rehabilitated. Thus, considerations of previously ignored aspects such as riparian and instream habitat and watershed dynamics must be included in urban nonpoint source assessment and abatement strategies.

The direct and indirect effects of sedimentation and the associated nutrient enrichment are becoming especially apparent in the larger mainstem rivers. Both sediment and nutrient enrichment impacts have largely been overlooked and will not only require a change in the status quo of water quality management but also in the interdisciplinary solutions and information gathering that demonstrates the character and magnitude of these impacts (36).

## Bioassessment of Urban Watersheds

Biological criteria and bioassessment methods can and do play a key role in several areas of nonpoint source management. As a basis for determining use impairments, biocriteria have played a central role in the Ohio Nonpoint Source Assessments (33, 37), the biennial Ohio Water Resource Inventory (305b report) (32), and watershed-specific assessments of which Ohio EPA completes from 6 to 12 each year. Biological criteria represent a measurable and tangible goal against which the effectiveness of nonpoint source pollution abatement programs and individual projects can be judged. Biological assessments, however, must be accompanied by appropriate chemical-physical measures, land-use considerations, and source information necessary to establish linkages between the land-use activities and the instream responses.

A great deal of uncertainty exists about the link between steady-state water quality criteria and ecological indicators. While we have observed biocriteria attainment with chemical water quality criteria exceedences in only a fraction of the comparisons, the chemical data are largely from grab samples collected during summer-fall low flow situations. In many cases, we have failed to detect chemical criteria exceedences during low flows, yet biocriteria impairment is apparent. The correspondence of biocriteria attainment with water quality criteria exceedences measured under elevated flows has not been observed with any regularity. Nonetheless, we have surmised that much of the biocriteria nonattainment observed in affected urban watersheds is due to water quality criteria exceedences that have occurred during elevated flow events that preceded the biological sampling. Reaching such a conclusion, however, is made possible only by examining other evidence beyond water column data.

In many urban settings, sediment chemical concentrations frequently are highly or extremely elevated compared with concentrations measured at least-affected reference sites. Contaminated sediments enter the aquatic environment during episodic releases from point sources and during runoff events from nonpoint sources. The correspondence between increasingly elevated sediment concentrations and declining aquatic community performance is demonstrated by Figure 5. A sediment classification scheme derived by Kelly and Hite (38) for Illinois streams was used to classify results for sediment chemical analyses at sites with corresponding biological data. Sediment chemical concentrations are classified as nonelevated, slightly elevated, elevated, highly elevated, and extremely elevated as the concentrations increase beyond the mean concentration at background sites. The results for four heavy metal parameters (arsenic, cadmium, lead, and zinc) commonly encountered in urban settings show that the frequency

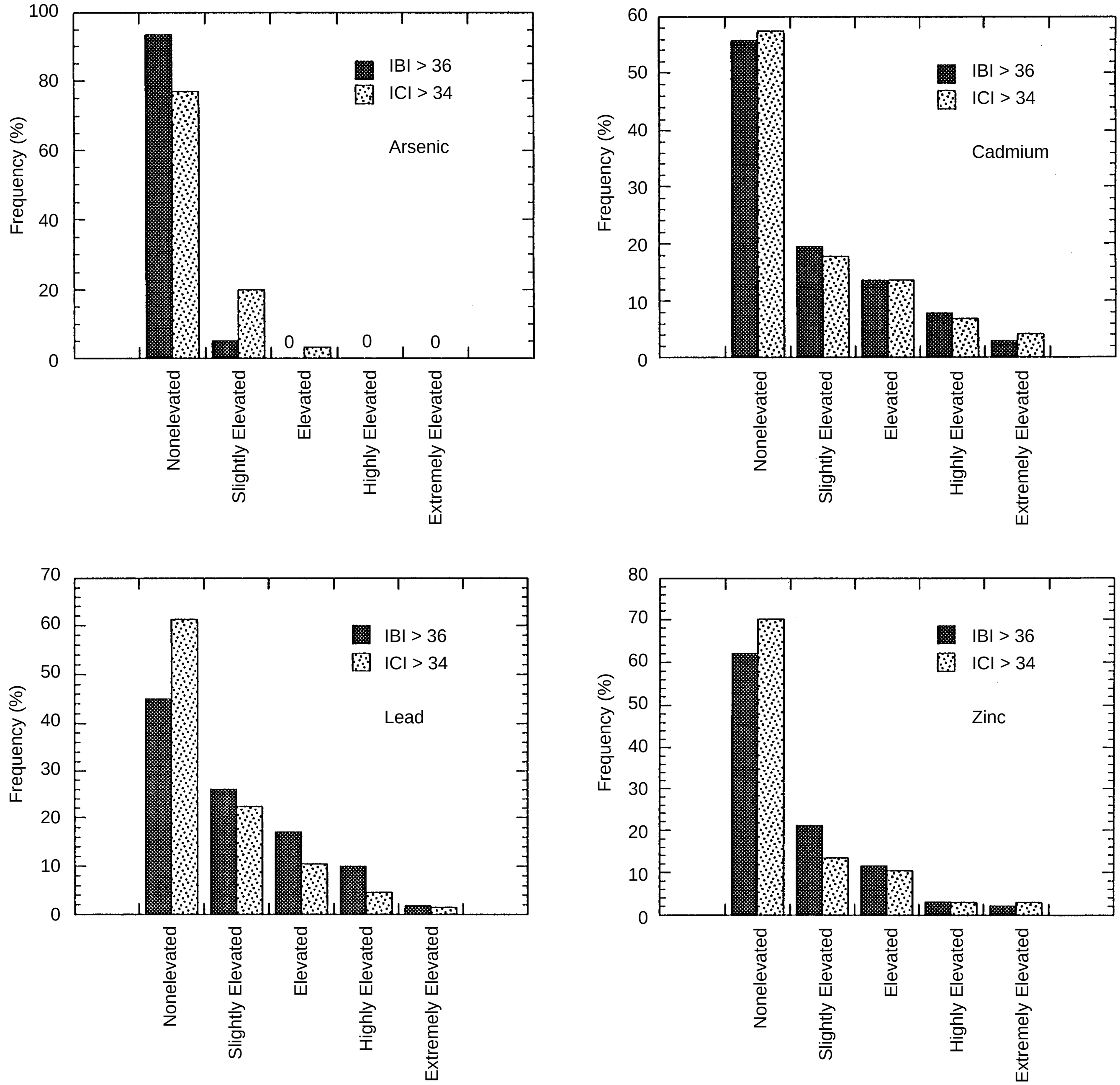



**Figure 5. The frequency of occurrence of IBI and ICI scores which attain the warmwater habitat biocriteria under increasingly contaminated levels of four heavy metals in bottom sediments. Based on data collected by Ohio EPA throughout Ohio between 1981 and 1989.**

of sites attaining the WWH use designation criteria for the IBI and ICI sharply decline as the sediment concentrations of these metals increase. For arsenic, no sites with highly or extremely elevated concentrations attain the biocriteria. For the remaining three parameters, in a few instances in each case, biocriteria attainment exists with highly elevated or extremely elevated sediment concentrations, but these are exceptions to the overall pattern.

For bioassessments to achieve their maximum effective use in the assessment of urban nonpoint sources, sampling and analysis should be based on a watershed design. An example of the use of biological criteria to evaluate aquatic life-use attainment/nonattainment in an urban watershed involves the Nimishillen Creek basin in northeastern Ohio (Table 1). This watershed is subject to a variety of point and nonpoint source impacts and is extensively affected by intensive urbanization in several

**Table 1. Aquatic Life-Use Attainment Status for the Existing and Recommended Aquatic Life-Use Designations in the Nimishillen Creek and Selected Tributaries Based on Data Collected From June to September, 1985**

| Use Designation | RIVER MILE Fish/ Invertebrate | IBI | MIwb | ICI[a] | QHEI[b] | Attainment Status[c] | Comment |
|---|---|---|---|---|---|---|---|
| **Nimishillen Creek** | | | | | | | |
| WWH | 14.2/14.2 | 30[d] | 6.7[d] | 22[d] | 60 | Non | Dst. East and Middle Branches |
| | 12.7/12.7 | 22[d] | 6.0[d] | 22[d] | 71.5 | Non | Cherry Ave. |
| | 11.7/11.7 | 20[d] | 4.8[d] | 12[d] | 81 | Non | Dst. West Branch (Gregory Galvanizing) |
| | 11.2/11.1 | 17[d] | 3.3[d] | 8[d] | 81.5 | Non | Dst. Hurford Run (Ashland Oil) |
| WWH | 10.2/10.3 | 19[d] | 3.1[d] | 10[d] | 72.5 | Non | Ust. Canton WWTP |
| | 8.8/8.8 | 19[d] | 2.3[d] | 8[d] | 85 | Non | Baum Rd. |
| | 6.7/6.7 | 16[d] | 3.6[d] | 2[d] | 80.5 | Non | Howenstine Rd. |
| | 3.2/3.2 | 24[d] | 4.2[d] | 6[d] | 91 | Non | Main St. |
| | 0.6/0.6 | 20[d] | 3.9[d] | 0[d] | 92 | Non | Ust. at mouth |
| **Sherrie (Sherrick) Run** | | | | | | | |
| LRW | 5.3/5.3 | 12[d] | N/A | P[d] | 33.5 | Non | |
| WWH | 4.1/4.1 | 17[d] | N/A | P[d] | 70 T | Non | Dst. Osnaburg Ditch |
| | 0.1/— | 22 | N/A | P[d] | 52 | Non | |
| **Osnaburg Ditch** | | | | | | | |
| MWH | 0.7/0.7 | 15[d] | N/A | P[d] | 42 T | Non | Ust. East Canton WWTP |
| | 0.1/0.1 | 12[d] | N/A | P[d] | 39 | Non | Dst. East Canton WWTP |
| **Hurford Run** | | | | | | | |
| LRW | 2.0/— | 12[d] | N/A | — | 34.5 | Non | Ust. Ashland Oil |
| | 1.8/— | 12[d] | N/A | — | 27 | Non | Dst. Ashland Oil |
| MWH | 1.2/— | 12[d] | N/A | — | 52.5 | Non | Dst. Domer Ditch |
| WWH | 0.3/— | 12[d] | N/A | — | 66 | Non | |
| | 0.1/— | 18[d] | N/A | — | 50.5 | Non | |
| **Domer Ditch** | | | | | | | |
| WWH | 0.5/0.4 | 23[d] | N/A | MG | 60 | Non | Ust. Timken |
| | 0.1/0.1 | 18[d] | N/A | P[d] | 54.5 | Non | Dst. Timken |
| **West Branch Nimishillen Creek** | | | | | | | |
| WWH | 5.9/5.9 | 27[d] | N/A | 18[d] | 53 | Non | At cemetery |
| | 3.2/3.2 | 17[d] | 4.8[d] | 20[d] | 59.5 | Non | Dst. McDowell Ditch |
| | 1.6/1.6 | 22[d] | 5.5[d] | 20[d] | 43.5 | Non | Ust. Tuscarawas St. |
| | 0.8/— | 24[d] | 6.2[d] | — | 34.5 | (Non) | Ust. Gregory Galvanizing |
| | 0.1/0.1 | 21[d] | 3.1[d] | 12[d] | 65 | Non | Dst. Gregory Galvanizing |
| **McDowell Ditch** | | | | | | | |
| MWH | 1.8/1.8 | 21[d] | N/A | F | 34 | Partial | Ust. Everhard Rd. |
| | 0.1/0.1 | 21[d] | N/A | F | 41 | Partial | At mouth |
| **Zimber Ditch** | | | | | | | |
| WWH | 3.8/3.8 | 40[ns] | N/A | G | 57 | Full | Regional reference site |
| | 1.8/2.4 | 29[d] | N/A | F | 42 | Non | Dst. Hoover Industrial Park |
| MWH | 0.9/1.1 | 23[d] | N/A | F | 31 | Partial | Ust. North Canton Ditch |
| | 0.6/0.6 | 23[d] | N/A | F | 31.5 | Partial | Dst. North Canton Ditch |
| **Rettig Ditch** | | | | | | | |
| Undesignated | 0.9/0.9 | 29[d] | N/A | F | 39 | Non | Channel modified |
| **North Canton Ditch** | | | | | | | |
| LRW | 0.1/0.1 | 32 | N/A | P | 46 | Full | Partially culverted (80-m zone) |

**Table 1. Aquatic Life-Use Attainment Status for the Existing and Recommended Aquatic Life-Use Designations in the Nimishillen Creek and Selected Tributaries Based on Data Collected From June to September, 1985 (Continued)**

| Use Designation | RIVER MILE Fish/ Invertebrate | IBI | MIwb | ICI[a] | QHEI[b] | Attainment Status[c] | Comment |
|---|---|---|---|---|---|---|---|
| **Middle Branch Nimishillen Creek** | | | | | | | |
| WWH | 11.4/11.4 | 45 | N/A | 30[ns] | 50 | Full | |
| | 10.4/10.4 | 27[d] | 5.8[d] | 22[d] | 38 | Non | Ust. State St. |
| | 8.0/8.0 | 34[ns] | 7.7[ns] | 30[ns] | 74 | Full | Dst. Werner-Church Rd. |
| | 6.8/6.8 | 35[ns] | 8.0 | 40 | 47 | Full | Regional reference site |
| | 5.0/— | 37[ns] | 7.6[ns] | — | — | (Full) | Ust. 55th St. |
| | 2.5/2.5 | 38 | 8.3 | 28[d] | — | Partial | Ust. Martindale Rd. |
| | 1.6/— | 43 | 8.5 | — | — | (Full) | Dst. State Route 62 |
| | —/0.8 | — | — | 10[d] | — | (Non) | |
| | 0.2/0.1 | 28[d] | 7.2[d] | 14[d] | 60 | Non | Cookes Park |
| **Swartz Ditch** | | | | | | | |
| MWH | 2.6/2.6 | 26 | N/A | F | 34 | Full | Ust. Smith-Kramer Rd. |
| | 1.2/1.2 | 33 | N/A | P[d] | 31 | Non | Ust. Church Rd. |
| | 0.2/0.3 | 34 | N/A | F | 45.5 | Full | Dst. Hartville Ditch |
| **Guiley (Hartville) Ditch** | | | | | | | |
| MWH | —/4.1 | — | — | P[d] | — | (Non) | Ust. Teledyne |
| | 3.4/— | 26 | N/A | — | 27 | (Full) | Ust. Hartville WWTP |
| | 2.3/2.3 | 33 | N/A | P[d] | 32 | Partial | Dst. Smith-Kramer Rd. |
| | 0.4/0.4 | 36 | N/A | F | 44 | Full | Gans Rd.-Dst. Culvert |
| **East Branch Nimishillen Creek** | | | | | | | |
| WWH | 8.6/8.6 | 39[ns] | N/A | 40 | 64.5 | Full | Regional reference site |
| | 6.4/6.3 | 33[d] | 6.8[d] | 26[d] | 51 | Non | Ust. J&L Steel |
| WWH | 4.7/4.7 | 29[d] | 6.4[d] | 4[d] | 80 | Non | Dst. J&L Steel |
| | 4.2/4.2 | 23[d] | 3.8[d] | 14[d] | 66 | Non | Dst. Louisville South WWTP |
| | 3.4/2.8 | 24[d] | 4.5[d] | 20[d] | 66 | Non | Dst. Louisville North WWTP |
| | 1.9/1.9 | 24[d] | 5.1[d] | 20[d] | 67.5 | Non | Ust. LTV Steel |
| | 0.1/0.1 | 31[d] | 8.2[d] | 14[d] | 60.5 | Partial | At mouth |

**Ecoregion Biocriteria: Erie/Ontario Lake Plain**

| INDEX - Site Type | WWH | EWH | MWH[e] |
|---|---|---|---|
| IBI - Headwaters | 40 | 50 | 24 |
| IBI - Wading | 38 | 50 | 24 |
| MIwb - Wading | 7.9 | 9.4 | 5.8 |
| ICI | 34 | 46 | 22 |

[a] Narrative criteria used in lieu of ICI: E = exceptional, G = good, MG = marginally good, F = fair, P = poor.
[b] All QHEI values are based on the most recent version of the index (28).
[c] Use attainment is parenthetically expressed when based on one organism group.
[d] Significant departure from ecoregion biocriteria; poor and very poor results are underlined.
[e] For channel modified areas.
Dst. = downstream
LRW = Limited Resource Waters
MIwb = modified Iwb
MWH = Modified Warmwater Habitat
ns = nonsignificant departure from WWH and EWH biocriteria (4 IBI or ICI units; 0.5 MIwb units).
Ust. = upstream
WWTP = wastewater treatment plant

areas. As with many of the Ohio watersheds that are more heavily affected by point and nonpoint sources, the majority of sampling sites either fail to attain the applicable biological criteria or are only in partial attainment. Out of 57 sampling sites in the entire watershed, only 11 (19 percent) fully attained the applicable biological criteria. These results demonstrate the degree of degradation that exists in most urban watersheds and the multiple source causes.

Another issue of critical importance to the management of urban watersheds is also apparent in Table 1, use attainability. Many of the use designations listed for the various streams of the Nimishillen Creek basin are recommended uses, meaning that a different aquatic life use applied at the time of the sampling. An important objective of the biological sampling conducted by Ohio EPA is to determine the appropriate aquatic life-use designation. If the results of the sampling and data analysis suggest that the existing use designation is inappropriate (or the stream is presently unclassified), the appropriate use is recommended. These recommendations are then proposed in a WQS rulemaking procedure and adopted after consideration of public input.

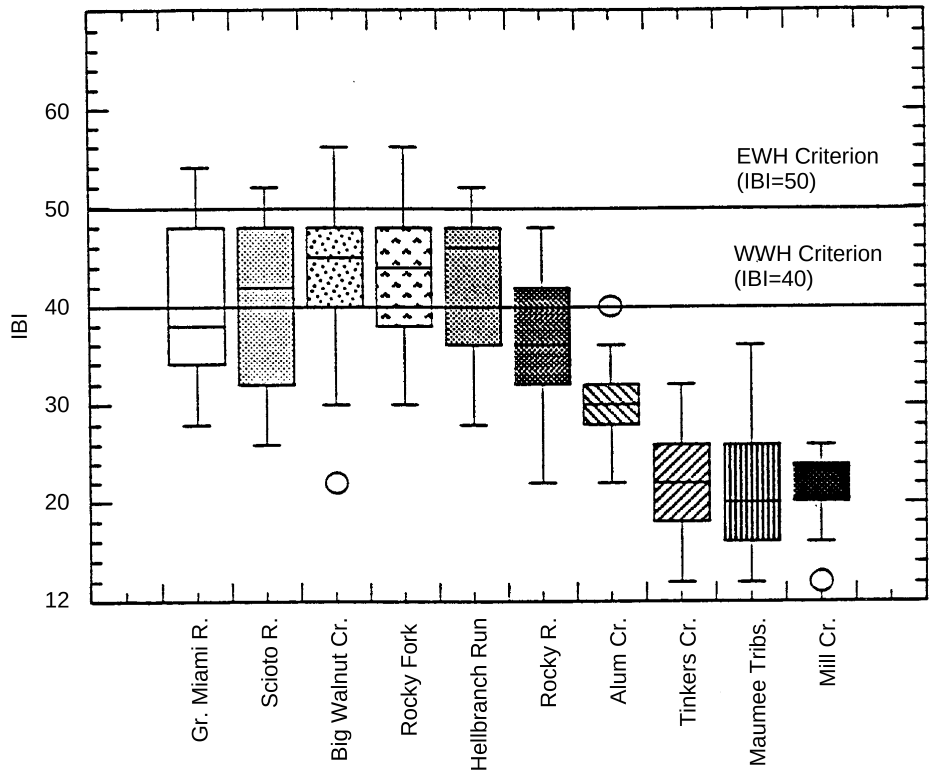
Figure 6 illustrates the relative distribution of IBI scores based on biological monitoring conducted by Ohio EPA in several urban and suburban watersheds throughout Ohio. These range in size from relatively small headwater streams (less than a 20-square-mile watershed area) to increasingly larger streams and rivers. For the smaller watersheds, there is a pattern of lower IBI scores and a subsequent loss of biological integrity with an increasing degree of urbanization. The baseline biological criterion for the WWH use designation is not attained by any (or only a few) sampling sites in the older urban watersheds, such as the Cuyahoga River and Little Cuyahoga River of northeastern Ohio and Mill Creek in Cincinnati. The IBI scores in these watersheds are indicative of poor and very poor water resource quality. The Rocky River basin is largely a suburban area of Cleveland upon which municipal wastewater discharges have had an extensive impact, but despite this the basin exhibits higher IBI scores. The highest IBI scores were observed in Rocky Fork (Columbus area), Taylor Creek (Cincinnati area), and Little Miami River (southwest Ohio) tributaries, which have only recently begun to be suburbanized. These three watersheds also lack some of the companion impacts of the older urban areas, namely, combined sewer overflows and industrial discharges.

For the larger streams and rivers, the pattern was similar, with the older urban areas exhibiting the lowest IBI scores and the less urbanized and suburban watersheds exhibiting higher scores, some of which attain the WWH criteria. The major exceptions, however, involve the two large mainstem rivers (Great Miami River and Scioto River) which exhibit higher IBI scores despite flowing within urban settings. This illustrates the influence of river and upstream watershed size on the ability of a river or stream to withstand increased urbanization. Both the Great Miami River and Scioto River mainstems originate in rural areas and are quite large when they enter the Dayton and Columbus urban areas. Thus, stream size relative to the watershed and the influence of land-use patterns are important to understanding and managing local nonpoint source impacts.

## Applications to Nonpoint Source Management

Steedman (24) observed the IBI to be negatively correlated with urban land use. The land use within the 10 to 100 $km^2$ area upstream from a site was the most important in predicting the IBI, which suggests that "extraneous" information was likely included if whole watershed land-use area was used. Steedman (24) also determined that the condition of the riparian zone was an important covariate (a measure of independent variation) with urban land use in addition to other factors, such as sedimentation and nutrient enrichment. A model relationship between these factors and the IBI was developed and provided the basis to predict when the IBI would decline below a certain threshold level with certain combinations of riparian zone width and percent of urbanization. In the Steedman (24) study, the domain of degradation for Toronto area streams ranged from 75-percent riparian removal at 0-percent urbanization to 0-percent riparian removal at 55-percent urbanization. These results indicate that it is possible to establish the bounds within which the combination of watershed land use and riparian zone condition must be maintained for a target level of biological community performance to persist. It seems plausible that such relationships could be established for many other watersheds, provided the database is sufficiently developed not only for biological communities but also for land-use composition and riparian corridor condition. Additionally including the concept of ecoregions and subecoregions should lead to the development of criteria for land use and riparian zones that would ensure the maintenance of biocriteria performance levels in streams and rivers over fairly broad areas without the need to develop a site-specific database everywhere.

Well-designed biological surveys can fit well into the watershed approach to nonpoint source management. Because the biota respond to and integrate all of the various factors that affect a particular water body, they are essentially the end product of what happens within watersheds. The important issue is that ambient monitoring be conducted as part of the nonpoint source assessment and management process, and that it be performed correctly in terms of timing, methods, and design. Monitoring alone is not enough, however. Federal, state, local, and private efforts to remediate nonpoint source impairments must include an interdisciplinary approach that goes beyond water column chemistry impacts to include the cumulative range of factors responsible for ecosystem degradation that has been documented over the past century. Existing regulations and standards have only been locally successful in reducing water resource declines attributable to watershed and riparian zone degradation. Effective protection and rehabilitation strategies require the targeting of large areas and individual sites (39) as well as the



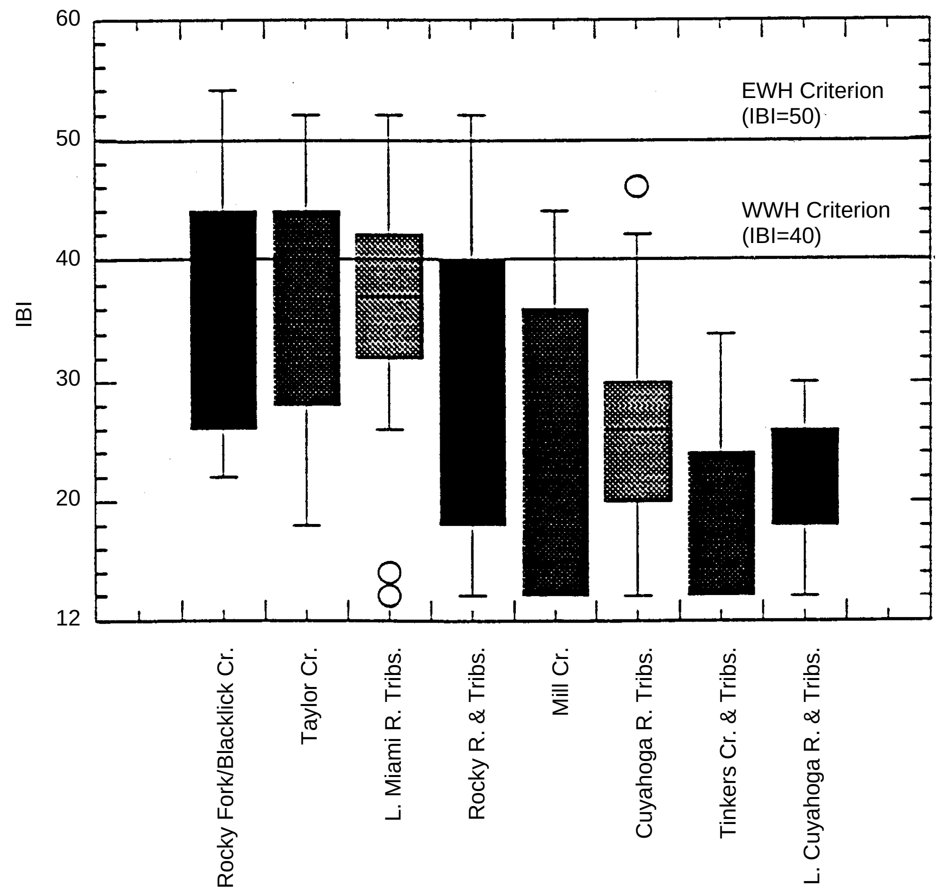




**Figure 6. IBI values observed in selected Ohio headwaters streams (drainage area <20 mi.$^2$; upper) and larger Ohio streams and rivers between 1981 and 1992. Box and whisker plots include all values recorded in each stream or stream/river assemblage.**

incorporation of ecological concepts in the status quo of land-use management practices and policies.

Ohio EPA has initiated the development of policies that will ensure a holistic approach to nonpoint source management. For example, we have specified a minimum width of two to three times the bank full channel width as necessary to protect riparian zones and ensure the integrity of instream habitat. This also ensures that the ability of the stream to assimilate nonpoint source runoff will be maintained. To be completely successful, however, this measure must be accompanied by the application of best management practices in the uplands. Such an approach goes well beyond a singular concern for the concentration of pollutants in the water column and must be incorporated into the total maximum daily load approach envisioned by the U.S. Environmental Protection Agency as an integral part of urban nonpoint source runoff management.

Thus, it seems that we have a choice in the management of urban nonpoint sources, as portrayed by Figure 7. Extending the traditional process by which we have managed chemical pollutants discharged by point sources during the past 15 to 20 years to nonpoint sources is exemplified by treating streams as once-through flow conduits that are essentially isolated from interactions with the landscape. This is commonly exemplified by simplified mass-balance approaches to establishing water quality-based effluent limitations for point sources using steady-state assumptions. While this approach has been successful in reducing point source loadings of commonly discharged substances, it holds much less promise for highly dynamic inputs from diffuse sources. For nonpoint source management to truly result in the restoration and preservation of biological integrity, we must regard streams as an interactive component of the landscape where multiple inputs and influences act together to determine the health of the aquatic resource.

Urban watershed management and protection issues will continue to develop as new information is revealed and relationships between instream biological community performance and watershed factors are better developed. Nonetheless, some of what we know now should be included in current management strategies. Urban and suburban development must become proactive; that is, developments must be designed to accommodate the features of the natural landscape and include common sense features such as setbacks from riparian zones. Regulatory agencies also share responsibility, particularly in resolving use attainability issues. Watersheds that exhibit the attainment of aquatic life-use biocriteria should be protected to maintain the current conditions. Frequently our attention seems to emphasize high quality or unique habitats; however,

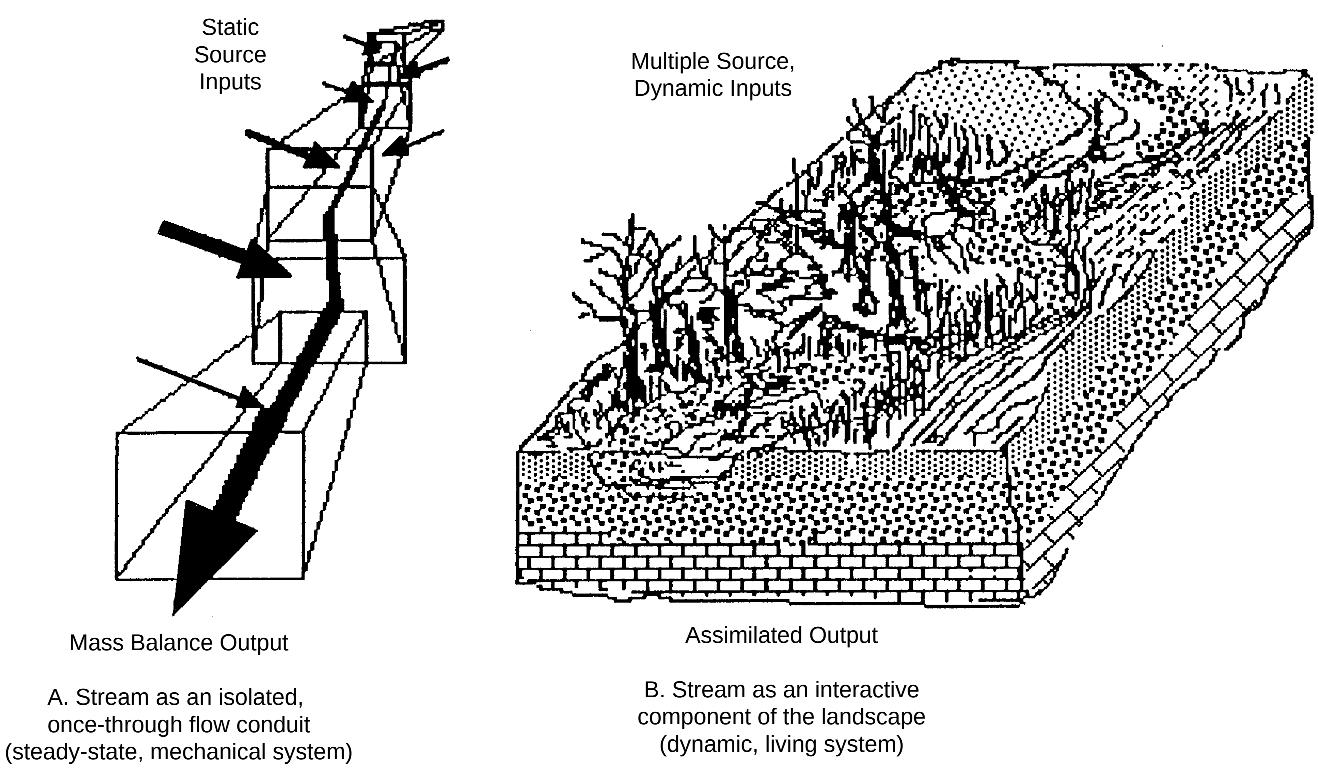



**Figure 7. Two views of a stream ecosystem: A. The stream is viewed as an isolated conveyance for static source wastes and runoff with the net water column output as a mass balance function of flow and concentration. B. The stream as an interactive component of the landscape with dynamic and multiple source inputs and assimilated output as affected by the surrounding land use, habitat, geology, soils, and other biotic and abiotic factors.**

water quality standards must be maintained where they are presently attained, if even minimally so. Strategies should also include the restoration of degraded watersheds where that potential exists. In systems where the degree of degradation is so severe that the damage is essentially irreparable, minimal enhancement measures should still be required, even though full use attainment is not expected. Biocriteria and bioassessments have an important and central role to play in this process.

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# *Overview of Contaminated Sediment Assessment Methods*

**Diane Dennis-Flagler**
**U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Illinois**

Urban runoff has significantly contributed to the contamination of lakes, rivers, and streams. After years of accumulation in the water, toxic chemicals have found their way to the bottom sediments. These contaminants can be directly toxic to fish and other aquatic organisms as well as significant sources of contaminants to wildlife. Human health effect concerns arise primarily from consumption of contaminated fish and water fowl. Assessing contaminated sediments is a difficult task due to the complex nature of the sediment matrix, contaminant mixtures, and the physical dynamics of the waterways. To determine the scope and extent of the sediment contamination at a particular site, a comprehensive sediment assessment program must be developed.

In recognition of the significance of the problem, the Assessment and Remediation of Contaminated Sediments (ARCS) program was authorized for 6 years—by Congress under Section 118(c)(3) of the Water Quality Act of 1987 and the Great Lakes Critical Program Act of 1990—to develop and demonstrate new and innovative methods both to assess and to treat contaminated sediments. The ARCS program developed an “Integrated Contaminated Sediments Assessment Approach” for use in the Great Lakes Areas of Concern (1). This approach includes:

- Sampling design and quality assurance
- Sample collection
- Chemical analysis
- Toxicity testing
- Benthic community structure survey
- Tumors and abnormalities

These six topics are the focus of this paper.

## Assessment Components

### *Sample Design and Collection*

The ultimate goal of assessment is to determine the scope and extent of contamination, including the magnitude and spatial bounds of the problem. Assessment needs direct sample design. Sediment sampling programs are most often undertaken to achieve one or more of the following objectives: to fulfill a regulatory testing requirement, to determine characteristic ambient levels, to monitor trends in contamination levels, to identify hot spots of contamination, and to screen for potential problems. These different objectives lead to different sampling designs. For example, a study for a dredging project may have a specific set of guidelines on sampling frequency, sample site selection methodology, and other parameters already determined by existing, specific guidance. The design for a study to track sediment contamination trends would expend its resources to sample fewer sites more frequently. A study to identify hot spots would concentrate efforts on fewer sites within zones known to be mostly contaminated, while an initial screening study might take few randomly distributed samples for analysis together with some “observation” samples to supplement the analytical results.

The most appropriate sample collection device for a specific study depends on the study objectives, sampling conditions, parameters to be analyzed, and cost. Three general types of devices are used to collect sediment samples: dredges, grab samplers, and corers. Core samples give by far the most complete information; thus, corers should be the sampler of choice whenever possible. Deep core sampling gives a three-dimensional picture of the situation. This allows characterization of the depth of contamination. Before a river or lake bottom is dredged in an effort to remove contamination, knowing whether more serious contamination will be uncovered is vital. All of this information guides remediation decisions.

The ARCS program concentrated on three levels of sampling data:

- *Historical data* can give some preliminary clues to what may be present at a site. Consideration of historical data can help to move the sample design process in the proper direction. Historical data have some limitations, however, that bear consideration. Often data are only available for surface sediments, and quality assurance may be in question.
- *Reconnaissance sampling data* involve characterizing a large area with "quick and dirty" screening tests on fewer samples. This data can help eliminate some of the parameters of concern, thus allowing more extensive testing of toxic substances present at the site.
- *Detailed assessment data* involve the more extensive chemistry and biological testing to fully characterize a hot spot.

### Chemical and Physical Analysis

Sampling efforts are performed with a variety of objectives in mind. Therefore, minimal chemical and physical parameter testing requirements vary between studies or programs. Some chemical and physical parameters, however, should be common to most programs unless evidence precludes their consideration:

- *Particle or grain size* is a physical parameter that determines the distribution of particles. Size is important because finer grained sediments tend to bind contaminants more than coarse sediments do.
- *Total organic carbon (TOC)* is an important indicator of bioavailability for nonionic hydrophobic organic pollutants.
- *Acid volatile sulfides (AVS)* have been found to be closely related to the toxicity of sediment-related associated metals.
- *Polyaromatic hydrocarbons (PAHs)* are semivolatile organic pollutants, several of which are potential carcinogens and are linked to tumors in fish.
- *Polychlorinated biphenyls (PCBs)* are chlorinated organic compounds once used for numerous purposes, including as a dielectric fluid in electrical transformers.
- *Pesticides* are synthetic compounds predominantly used in agriculture to control crop-damaging insects.
- *Other semivolatiles* include acid/base neutral compounds (ABNs) such as phenols, naphthenes, and toluenes.
- *Heavy metals* are naturally occurring in the environment, but an excess of metals can be an indication of anthropogenic contamination; heavy metals can be toxic to benthic organisms.

For a typical Great Lakes site, grain size, TOC, and AVS analyses should be done; the other five analyses should be performed accordingly. For example, if heavy metals in a particular area are not a problem, they could be omitted from the scheme. Also, if certain other contaminants are suspected in an area, they should be included as test parameters (e.g., tributyl tin and methyl mercury).

### Toxicity Testing

Although chemical analysis is an illuminating part of the assessment process, chemical analysis alone does not determine impacts. Bioavailability is key to determining whether or not toxic contaminants will cause effects. For example, it is possible to find a situation where high concentrations of contaminants are present but no toxic effects are manifested in the benthic community; in such a situation, the contaminants may not be bioavailable to the benthic community. In any case, further toxicity testing would be required. One way to evaluate bioavailability is by performing toxicity tests. Toxicity tests measure the effects of sediment contamination test organisms. Test organisms can be exposed directly to sediments (solid phase) or to sediment slurries called elutriates.

The ARCS program evaluated over 40 toxicity tests during the assessment program at three priority areas of concern. Based on the results of the ARCS program, a battery of tests should include Microtox and *Daphnia magna* (7-day, three-brood survival reproduction solid phase assay) because they are good screening assays, relatively sensitive, discriminatory, and well correlated with other assay responses. In addition, one or two of the following tests should be included in the assay battery: *Pimephales promelas* (larval growth solid phase), *Hyalella azteca* (7-day survival solid phase), *Ceriodaphnia dubia* (three-brood survival and reproduction, solid or elutriate phase), and *Hexagenia bilineata* (10-day survival and molting, solid or elutriate phase).

### Benthic Community Survey

Benthic communities are communities of organisms that live in or on sediment. In most benthic community structure assessments, primary emphasis is placed on determining the species that are present and the distribution of individuals among those species. Information on benthic community composition and abundance is typically used in conjunction with information in the scientific literature to infer the distribution of species and individuals. Because sediment quality affects all major structural and functional attributes of benthic communities in generally predictable ways, benthic community structure assessment is a valuable tool for evaluating sediment quality and its effects on a major biological component of freshwater ecosystems. Specific assessment methods are available to complement the chemical and toxicological portions of the sediment quality assessment.

Freshwater benthic macroinvertebrate communities are used in the following ways to assess the quality of the water resource:

- Identification of the quality of ambient sites through a knowledge of the pollution tolerances and life history requirements of benthic macroinvertebrates.
- Establishment of standards based on community performance at multiple reference sites throughout an ecoregion or other regionalization categories.
- Comparison of the quality of reference sites with test sites.
- Comparison of the quality of ambient sites with historical data to identify temporal trends.
- Determination of spatial gradients of contamination for source characterization.

### *Tumors and Abnormalities*

Tumors and other abnormalities are another useful assessment tool. These abnormalities are believed to be caused by contaminants present in the sediments, specifically PAHs. A typical use of this type of study would be to analyze for tumors and abnormalities before and after cleanup to see if a change in the incidence rate occurred. In the ARCS program, investigation of tumors and abnormalities helped to characterize the different areas of concern. For example, in the Ashtabula and Buffalo Rivers we found numerous liver and external abnormalities in Brown Bullhead, such as lip papillomas, preneoplastic lesions, and neoplastic lesions.

## Interpretation and Use of Data

All data are useless without an interpretation scheme. Using or looking at data in isolation can lead to false conclusions. Therefore, it is important to look at all aspects of data using some type of integrated process to aid decision-making.

### *Data Depiction*

Data cannot be easily interpreted from tables. Data need to be depicted in a visual manner, such that hot spots, gradient depth information, and trends are evident. One way to accomplish this goal is to make a map of the site and plot data results on the map. A three-dimensional map can be most useful in data depiction.

### *Sediment Quality Values*

As stated before, the numbers obtained from chemical testing are not very significant by themselves. If you have a gray-area situation, in which the chemistry numbers are high but toxicity or biological alteration is not necessarily evident, deciding whether this is or will become a problem may be difficult. In such a case, comparison of one's particular program numbers with existing numbers could give information on how to proceed. There are three general types of sediment quality values (2):

- *Equilibrium partitioning* is a theoretical approach that focuses on predicting the chemical interactions between sediments, interstitial water (i.e., the water between sediment particles), and contaminants. Chemically contaminated sediments are expected to cause adverse biological effects if the predicted interstitial water concentration for a given contaminant exceeds the chronic water quality criterion for that contaminant.
- *The empirical effects-based approach* (e.g., sediment quality triad or apparent effects threshold) combines measures of sediment chemistry, sediment toxicity, and/or benthic infauna communities to determine the overall sediment quality.
- *National status and trends* is a statistical approach that uses chemical data assembled from modeling laboratory and field studies to determine the ranges in chemical concentration that are rarely, sometimes, and usually associated with toxicity.

Each approach has advantages and disadvantages. The best approach is selected based on each programs' particular needs.

## Risk Assessment

After studying the data received from the chemistry, toxicity, and environmental impact analysis, the final assessment step is an evaluation of associated risk to human, aquatic, and wildlife. What is the risk now, and what is it potentially? This involves evaluating exposure to and impacts resulting from contact with contaminated sediments and media contaminated by sediment contaminants. If several sites are involved, a prioritization system may be needed as a decision-making tool for remedial actions.

The ARCS program used two levels of evaluation: baseline and comprehensive hazard evaluations. Baseline human health hazard evaluations were performed for all five priority demonstration areas and were developed from available site-specific information. The baseline hazard evaluations described the hazards to receptors under present site conditions. This baseline assessment also examined all potential pathways for human exposure to sediments for each given location. Comprehensive hazard evaluations were performed for the Buffalo River and Saginaw Bay areas. Results from ARCS studies showed that consumption of contaminated fish provided the greatest risk to human health.

## Conclusions

There are a number of approaches to the assessment process. The main components are sample design, chemical and physical analysis, biological testing and data interpretation. Within that framework, choices are made as to what course to follow. Regardless of which assessment path one takes, each phase of the assessment process should be carefully considered and tailored to the needs and goals of that particular program. All data must be integrated for decisions to be based on a preponderance of evidence and to yield the most definitive of results.

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# *Linked Watershed/Water-Body Model*

**Martin Kelly**
**Southwest Florida Water Management District, Tampa, Florida**

**Ronald Giovannelli and Michael Walters**
**Dames and Moore, Inc., Tampa, Florida**

**Tim Wool**
**AScI, Athens, Georgia**

## Abstract

With passage of the state's Surface Water Improvement and Management (SWIM) Act of 1987, the Southwest Florida Water Management District realized a need for an integrated eutrophication model incorporating both a watershed loading model and a water-body response model. In addition, because many watershed models depend on land use and soils mapping data, a modeling system that could take advantage of data already stored in the district's geographical information system (GIS) would be useful.

This paper describes the desirable attributes of such a modeling system, the means used to select the appropriate model components, the actual modeling system developed, and an application of the model. The modeling system is constructed around two U.S. Environmental Protection Agency supported models—Storm Water Management Model (SWMM) and Water Quality Analysis Simulation Program Model (WASP4)—and is linked to the ARC/INFO GIS. Rather than the details of SWMM or WASP4, the paper focuses on the SWMM/WASP Interactive Support Program (SWISP), the interactive, menu-driven user environment that allows for the easy execution of the linked watershed/water-body modeling system of programs. With SWISP, the user can view and edit input data sets as well as execute and graphically postprocess the results.

The modeling system is being tested and refined sequentially on three test sites. The paper presents the results of testing to date on a specific case study: Lake Thonotosassa, a hypereutrophic, 800-acre lake in Hillsborough County, Florida. The objective of the modeling is to allow for the assessment of various restoration strategies for improving in-lake water quality. The modeling system, which is PC based and in the public domain, will be available for public release in the fall of 1993, along with a user's manual.

## Introduction

With passage of the state's Surface Water Improvement and Management (SWIM) Act of 1987, the Southwest Florida Water Management District (SWFWMD) realized a need for an integrated eutrophication model incorporating both a watershed pollutant loading model and a water-body response model. In addition, because many watershed models depend on land use and soils mapping data, a modeling system that could take advantage of data already stored in the district's geographical information system (GIS) would be useful. The stated objective of the watershed/water-body modeling project was "to select and/or link a watershed(s) and water-body eutrophication model for use in prioritizing land-use management and pollution control strategies and evaluating the effects of implementation of best management practices (BMPs) on in-lake water quality and natural systems."

A variety of watershed models exist that make it possible, within limited degrees of certainty, to evaluate the effects of land-use practices on receiving waters. These models are used to prioritize watersheds that contribute the greatest loading to a water body. When coupled with an appropriate model of the receiving water body, the model system can be used to predict how changes in land use will affect the receiving body, both in terms of water quantity and quality.

A watershed model is an important planning tool for evaluating the contributions from existing conditions and projecting contributions under different scenarios. A watershed/water-body model system allows those using them to make decisions regarding alternative land use, zoning, treatment, and BMP options, thus altering constituent loadings to a receiving water body.

Water quality/ecological models are designed to mimic in-waterbody dynamics as the result of inputs and to predict trophic state or other conditions of interest. These models allow the modeler to predict lake conditions based on known or projected inputs, and thus evaluate how changes in loading will affect the overall health of a water body. Decisions with regard to how much of a load reduction is required to produce desired in-lake effects can be made, and the benefits of implementing a particular corrective strategy can be assessed.

From a water-body management perspective, it is desirable to have as a decision tool a linked model that couples the attributes of both watershed and water-body models. With such a model, it would be possible to evaluate how changes in land use will, for example, affect the trophic state (and other states) of a surface water body.

## Model Attributes

Prior to selecting a consultant, district staff developed a list of 13 desirable attributes of a linked watershed/water-body model (LWWM):

- Data can be input directly into the linked model from the district's GIS (ARC/INFO) database.
- The model system should consist of "off the shelf" watershed and water-body models, although some customizing may be required. (Proprietary software is not acceptable.)
- Calibration and validation data requirements should not be excessive.
- The model can be applied to most Florida aquatic systems with the watershed component suitable for estuarine systems.
- The model has a storm event or seasonally based watershed component, yet it is capable of yielding annualized values.
- The output of the watershed model component should be fully compatible with the input of the water-body model component.
- The model should be user-friendly, menu-driven, interactive, and fully documented.
- The water-body model considers the physical, chemical, and biological parameters and processes necessary to simulate the eutrophication process and attendant water quality conditions.
- The model is sensitive to eolian, sediment, and ground-water inputs.
- The water-body model should consider the temporal and spatial variation as required to simulate critical water quality conditions and processes.
- The model should be sensitive to trophic dynamics and exchanges between trophic levels.
- The water-body model should predict the trophic state using existing empirical relationships already developed for Florida lakes.

## Model Selection

Dames and Moore, Inc., was selected to develop the district's LWWM. The district also established a modeling technical advisory committee (TAC) composed of various recognized modeling and GIS experts from other agencies, academia, and private consulting firms. The primary goal of the TAC was to aid the district and its consultant in finalizing modeling goals and the list of desirable model attributes to be used in an evaluation of existing candidate models. One of the initial tasks accomplished by Dames and Moore was a literature and model comparison report (1) with recommended models to be used in the proposed LWWM. This review focused on model capabilities with regard to the overall LWWM project objectives and did not include a rigorous investigation of the background and theory behind each model.

Dames and Moore, following the examples of Basta and Bower (2) and Donigian and Huber (3), developed specific evaluation criteria to objectively review candidate models consistent with district objectives. Dames and Moore, with the aid of the TAC and before identifying available models, developed four criteria to be used on a preselection basis to identify candidate models for further consideration:

- The models must have written documentation.
- The models must be maintained, either formally (i.e., funded model caretaker) or informally (through active use and application).
- The models must be PC based or have the capability of being easily transportable to the PC environment.
- The models must be nonproprietary.

Based on the above criteria and considering district requirements for review of certain specifically named models, a first-cut list of candidate models was developed followed by a final list of candidate models (Table 1).

The modeling TAC was relied on heavily to eliminate models from further consideration and ultimately arrived at the two selected models, SWMM and WASP4. The rationale for eliminating certain models is detailed by Dames and Moore (1); it was decided that the modeling system should rely on a single watershed model. After considerable discussion, certain models were

**Table 1. List of Final Candidate Models Evaluated by Dames and Moore, Inc., for Possible Incorporation in the SWFWMD's Linked Watershed/Water-Body Model System (1)**

| Watershed Models | Water-Body Models |
|---|---|
| AGNPS | BATHTUB |
| ANSWERS | BETTER |
| CREAMS | CE-QUAL-R1 |
| DR3M-QUAL | CE-QUAL-W2 |
| EPA-FHWA | HSPF |
| EUTROMOD | NUTRIENT LOADING/TROPHIC STATE (EUTROMOD) |
| GLEAMS | QUAL2EU |
| HSPF | WASP4 |
| NPSLAM | WQRRS |
| STORM | |
| SWMM | |
| SWRRB | |

eliminated because of their primarily rural or agricultural applicability, other models were eliminated on the basis of limited maintenance, and considerable in-house debate and discussion centered on the advantages and disadvantages of "mechanistic" versus "empirical" type models. Despite its selection, there was concern that SWMM was too complicated to use without extensive training and experience and that this would affect the desirable attribute of being user friendly and easy to apply (or misapply); this was considered a disadvantage common to all "mechanistic" models considered. SWMM is primarily an urban model, and although it has been applied in nonurban areas successfully, the erosion and sedimentation capabilities are not as detailed as most rural or agricultural models. Another disadvantage of SWMM is that subbasins must be defined homogeneously with respect to land use for the water quality routines, and this restriction would limit to some extent the enhancement that could be easily afforded by a GIS linkage (1). Similar type considerations as those mentioned above were used to eliminate candidate water-body models from further consideration.

Eventually, WASP4 was selected as the appropriate "mechanistic" model to complement the watershed loading model. The TAC noted that the model was well maintained, tested, and documented. Although identified as the most complex of the selected water-body models, it was also the most flexible because of its ability to simulate processes, which allows it to be used at either a screening or predictive level depending on the availability of data, the experience of the user, and the objective of the application. Although flexible, the TAC indicated that WASP4 was still perceived as being extremely data intensive (1).

Ultimately, SWMM and WASP4 were selected because these models were determined to be "sufficiently complex to be usable for the most data intensive studies, but have the capability of 'turning off' or 'zeroing out' components such that the model can be made simple. The models are public domain, and both are supported by the EPA. In addition, full documentation is available for both models, and they have each been well tested, including several applications in the southwest Florida area" (1). The models selected were not the best for every application; however, they were considered to be those that best met the objectives of the SWFWMD.

## Linked Watershed/Water-Body Modeling System Development

The LWWM incorporates three major environmental modeling components:

- Runoff (point and nonpoint)
- Hydrodynamic/Hydraulic routing
- Time variable water quality modeling

In essence, the LWWM operates as follows:

- It obtains land-use and soil-type information from ARC/INFO coded output.
- It incorporates this information into the runoff component of SWMM.
- SWMM calculates event-driven runoff loads of both point and nonpoint sources.
- The LWWM uses the hydrodynamic model, RIVMOD, to describe the longitudinal distributions of flow in the investigated water body.
- WASP4 incorporates these loads, flow distributions, and water quality information and simulates water-body interactions.

A schematic of the above program linkage is shown in Figure 1.

The LWWM was developed to allow engineers and scientists to rapidly evaluate the effects of both point and nonpoint source loads on receiving waters. The LWWM model obtains land-use information from a GIS that can be used to swiftly generate land-use and soil-type data for the runoff component of the LWWM system, SWMM. The SWMM model calculates event-driven runoff loads for both nonpoint and point sources. This time series of loads and water quantity runoff is then used as input for the receiving water model, WASP4 (EUTRO4). The information generated by the models will be accessible to users via interactive graphs and other user-friendly interfaces.

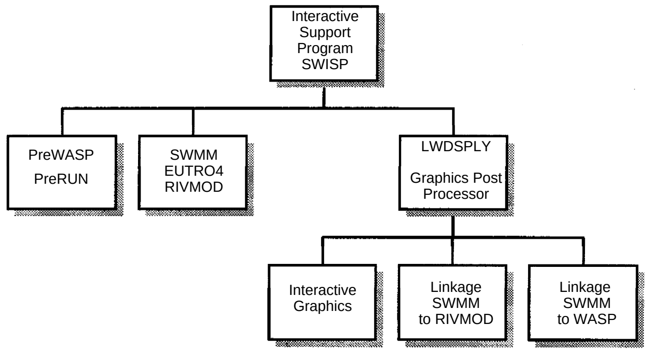


**Figure 1. Linked watershed/water-body model (LWWM).**

### *Geographical Information System Interface*

A GIS is a computer program used for the entry, management, analysis, and display of geographic or mappable information. GIS systems typically include all of the functions of a computer-aided design (CAD) system, as well as the powerful analytical and modeling capabilities of a full-featured relational database. The power of a GIS lies in its ability to derive problem-solving information from existing data through such techniques as map overlays and modeling, and to store this information in an organized, usable form.

GIS analytical techniques are applied to generate automatically the input data sets for the SWMM watershed model. The software used for development of these data sets is ARC/INFO, an industry-standard GIS from Environmental Systems Research Institute (ESRI). This software is the primary GIS platform in use at the SWFWMD and at all other water management districts throughout the state. Several other federal, state, regional, and local agencies have also adopted ARC/INFO as a standard and are preparing comprehensive geographic databases in this format. The SWFWMD has compiled an extensive geographic database of the entire district in an ARC/INFO format, including detailed coverages for the U.S. Department of Agriculture Soil Conservation Service (SCS) soils, land use and cover, and basin boundaries. These data are compiled using automated ARC/INFO techniques to generate an input data file for the LWWM.

### *SWMM*

SWMM (4) is a comprehensive mathematical model for the simulation of urban water quantity and quality in storm and combined sewer system. All aspects of urban hydrologic and water quality cycles are simulated. SWMM was developed between 1969 and 1971 by a consulting team under contract with the U.S. Environmental Protection Agency (EPA). It was one of the first such models and has been continually maintained and updated. The SWMM model is perhaps the best known and most widely used urban quantity/quality models in existence today.

SWMM simulates real storm events on the basis of rainfall hyetographs, land use, topography and system characterization to predict outcomes in the form of quality and quantity values. SWMM is composed of various computational blocks that can be run as stand-alone programs. The LWWM simplifies this process by selecting the appropriate blocks to run. The blocks used by LWWM and their function are as follows:

- *Runoff block:* Performs hydrologic and water quality modeling with elementary hydraulic routines.
- *Combine block:* Combines interface files to aggregate results of multiple runs.
- *Rain block:* Processes National Weather Service (NWS) precipitation data from magnetic tape or disk.

All other computational blocks within SWMM are either not applicable to the LWWM model or their function is already incorporated within the LWWM (i.e., graphic and tabular processing of output).

The LWWM model uses SWMM Version 4.2 but has been tested successfully with older versions.

### *RIVMOD Implementation*

RIVMOD is a dynamic numerical, hydrodynamic riverine model that describes the longitudinal distributions of flows in a one-dimensional water body through time. The primary criteria for selecting RIVMOD is the need to describe spatially varying flows in a water body through time. The model is applicable to rivers, streams, tidal estuaries, reservoirs, and other water bodies where the one-dimensional assumption is appropriate. RIVMOD solves the governing flow equations in a manner that allows prediction of gradually or highly varying flows through time and space. The model has the capability of handling flow or head as boundary conditions. The specification of head as a boundary condition allows use of the model where an open boundary is required (e.g., an estuary or a river flowing into a lake). Algorithms are employed in RIVMOD to allow it to provide WASP4 with flows, volumes, and water velocities.

### *WASP Implementation*

The WASP4 modeling system (5) was designed to provide the generality and flexibility necessary for analyzing a variety of water quality problems in a diverse set of water bodies. The model considers the hydrodynamics of large branching rivers, reservoirs, and estuaries; the mass transport in ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters; and the kinetic interactions of eutrophication-dissolved oxygen and sediment-toxic chemicals.

WASP4 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. The flexibility afforded by the Water Quality Analysis Simulation Program is unique. WASP4 permits the modeler to structure one-, two-, and three-dimensional models; allows the specification of time-variable exchange coefficients, advective flows, waste loads, and water quality boundary conditions; and permits tailored structuring of the kinetic processes, all within the larger modeling framework, without having to write or rewrite large sections of computer code.

WASP4 simulates the movement and interaction of pollutants within the water using two programs to simulate two of the major classes of water quality problems: conventional pollution (involving dissolved oxygen, biochemical oxygen demand, nitrogen, phosphorus, and eutrophication) and toxic pollution (involving organic chemicals, metals, and sediment).

Because of WASP4's generalized framework and dynamic structure, it is relatively easy to link it to other simulation models. WASP4 was modified to read loads from an external file created by SWMM. This allows WASP4 to update its point and nonpoint source loading information daily.

### *SWMM/WASP Interactive Support Program (SWISP)*

SWISP (Figure 2) is an interactive, menu-driven user environment that allows for the easy execution of the LWWM system of programs. SWISP allows you to view and edit WASP/RIVMOD/SWMM input datasets as well as execute and postprocess the results. SWISP is the Windows of the LWWMs; once the user executes SWISP, the user can perform all functions related to all the simulation models. SWISP provides file management, which allows the user to select a file or a set of files to activate for manipulation and/or execution. SWISP automatically loads the correct simulation model based on the type of input dataset selected; upon execution of the model, SWISP provides the input data file names that will be executed. When the simulation is completed, SWISP is automatically reloaded so that the results may be postprocessed.

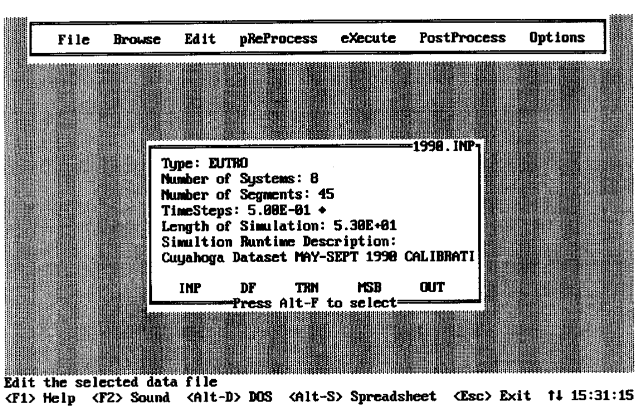


**Figure 2. SWMM/WASP Interactive Support Program (SWISP).**

### *SWMM Runoff Preprocessor (PreRUN)*

The PreRUN program (Figure 3) was developed to aid the user in the development of SWMM RUNOFF block input datasets (SWMM Version 4.2x and higher). PreRUN provides intuitive data entry forms that successful guide the user through the development of syntactically correct datasets. Additionally, the PreRUN program can import a GIS file that is created before executing the preprocessor. The GIS interface file provides soil-type and land-use classifications to the PreRUN program so that the user can quickly give parameters to the SWMM Runoff block. PreRUN is designed to work with or without the GIS interface file.

Landuse WorkSheet

| | | Land Use Delineation (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Hi Residen | Me Residen | Lo Residen | Agricultur | Industrial | |
| ID (No) | Area (acres) | 1 % | 2 % | 3 % | 4 % | 5 % | Total % |
| 90001 | 346.05 | 3.46 | 5.78 | 33.70 | 49.63 | 6.87 | 99.44 |
| 90002 | 417.15 | 4.27 | 6.53 | 69.06 | 9.68 | 0.34 | 89.88 |
| 90003 | 623.81 | 25.18 | 19.06 | 34.54 | 17.94 | 2.28 | 99.00 |
| 90004 | 748.00 | 12.45 | 19.56 | 38.14 | 21.65 | 7.56 | 99.36 |
| 90005 | 911.72 | 40.44 | 14.90 | 27.98 | 7.74 | 8.53 | 99.59 |
| 90006 | 535.13 | 13.70 | 16.78 | •24.77 | 37.83 | 6.65 | 99.73 |
| 90007 | 76.31 | 0.00 | 4.07 | 45.73 | 28.57 | 0.00 | 78.37 |
| 90008 | 881.75 | 34.88 | 21.15 | 19.09 | 21.40 | 3.31 | 99.83 |
| 90009 | 235.52 | 25.06 | 15.38 | 20.31 | 30.18 | 8.24 | 99.17 |
| 90010 | 346.05 | 3.46 | 5.78 | 33.70 | 49.63 | 6.87 | 99.44 |
| 90011 | 417.15 | 4.27 | 6.53 | 69.06 | 9.68 | 0.34 | 89.88 |
| 90012 | 623.81 | 25.18 | 19.06 | 34.54 | 17.94 | 2.28 | 99.00 |
| 90013 | 748.00 | 12.45 | 19.56 | 38.14 | 21.65 | 7.56 | 99.36 |
| 90014 | 911.72 | 40.44 | 14.90 | 27.98 | 7.74 | 8.53 | 99.59 |
| 90015 | 535.13 | 13.70 | 16.78 | 24.77 | 37.83 | 6.65 | 99.73 |
| 90016 | 76.31 | 0.00 | 4.07 | 45.73 | 28.57 | 0.00 | 78.37 |

Sub-basin area in acres

**Figure 3. SWMM Runoff Preprocessor (PreRun).**

The power of the PreRUN preprocessor lies in its ability to import a GIS interface file. The GIS file contains land-use and soil classification data for user-delineated watershed subbasins; this information is used by PreRUN to develop area weighted calculations for the SWMM model.

### *PreWASP Interactive Preprocessor (PreWASP)*

The PreWASP program (Figure 4) aids the user in the development of a WASP4 eutrophication input dataset. The preprocessor provides predefined environments (ponds, lakes, rivers, estuaries) that can be modified to match site-specific geometries, or the user may elect to build one from scratch. The PreWASP program allows the user to rapidly develop an input dataset by providing forms that can be filled out quickly using several "Quick Fill" edit functions. The PreWASP program allows the user to select the level of complexity at which to apply

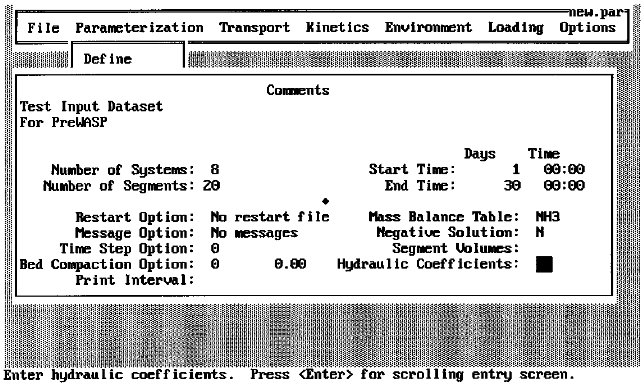


**Figure 4. PreWASP Interactive Processor (PreWASP).**

the model and provides data forms that are needed to accomplish that level of complexity.

### *Linked Water-Body/Watershed Postprocessor (LWDSPLY)*

The interactive graphical postprocessor LWDSPLY allows the user to rapidly visualize the results of WASP, RIVMOD, DYNHYD, and SWMM simulations. LWDSPLY and SWISP are the only software needed to process the large array of result files that can be produced from simulations of the models contained in the LWWM. LWDSPLY allows the user to view the results both graphically and tabularly and has options for exporting data to spreadsheets. LWDSPLY has the capabilities to process more than one simulation result file at a time (the files must be from the same model), and allows the plotting of up to four graphs on the screen simultaneously. These four plots (view ports) can be manipulated individually to show different results. As with all the programs, context-sensitive help is available at any time within the program by simply pressing F1 for help or ALT-H for a listing of the keyboard map (Figure 5).

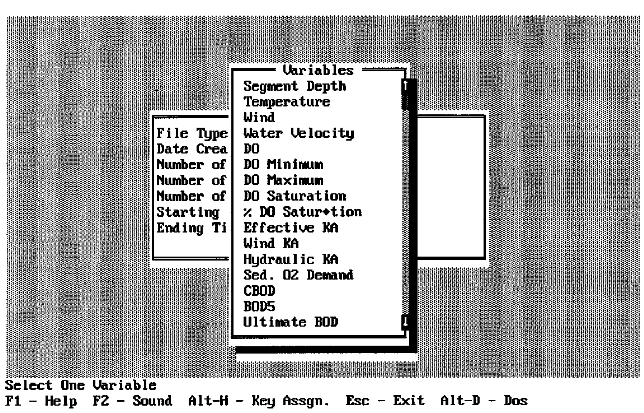


**Figure 5. Linked Water-Body/Watershed Postprocessor (LWDSPLY).**

The LWDSPLY program allows the user to view (Figure 6), plot, and export information very rapidly. All simulation results can be plotted or written to an ASCII text table or exported to a spreadsheet file. LWDSPLY also provides the algorithms for formatting the output of one model into the input of another.

### *Linking SWMM to WASP4*

SWMM and WASP4 are linked using the LWDSPLY program. The linkage is generic and allows the user to link SWMM results to either the WASP organic or eutrophication model. This linkage is accomplished by creating a SWMM combine block interface using the ASCII combine block option. PreRUN is set to create this file by default. The user must select the WASP4 (TOXI or EUTRO) model with which the SWMM file is to be linked; this allows LWDSPLY to configure itself for the correct output.

Once the appropriate linkage type has been selected, the user is then required to map the appropriate SWMM conduit IDs to WASP segments (Figure 7). Note that you can map more than one conduit's ID to a WASP segment; LWDSPLY will combine the output. LWDSPLY will not check any errors regarding the mapping, so the burden is on the user to fill this table out correctly. The figure below shows the data entry screen for the basin to segment mapping. Note that all the conduit IDs do not need to be mapped out to WASP segments; the user only needs to be concerned with the conduits that affect the water body.

Once the conduit to segment mapping has been completed, the SWMM runoff constituents must be mapped to the WASP4 state variables. The user must map the SWMM state variables to the WASP state variables. The linkage allows the user to fractionate a SWMM state variable to several WASP state variables. The example given below shows the mapping of total nitrogen (calculated by SWMM) into three state variables of WASP's EUTRO4 ($NH_3$, $NO_3$, and organic nitrogen). To accomplish this, the user must specify the percentage of the total SWMM constituent runoff mass that will go into each WASP system. This option is presented to the user because SWMM typically calculates mass runoff for total nitrogen and total phosphorus, while WASP needs nitrogen loaded as ammonia, nitrate, and organic nitrogen, as well as phosphorus loaded as orthophosphate and organic phosphorus. There is no error checking done here. The percentages converted can be less than or greater than 100 percent.

When the user is completed with the mapping functions, LWDSPLY will prompt the user for a filename to which to write the nonpoint source interface file. WASP expects the nonpoint source files to have the extension .NPS.

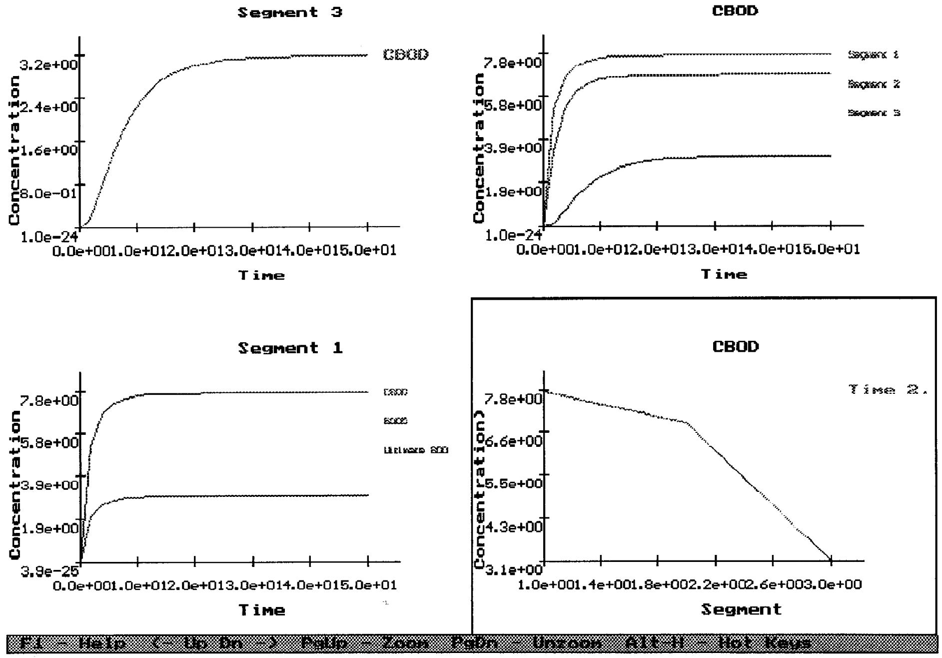


**Figure 6. Viewing data in the LWDSPLY.**

SWMM Constituent to WASP System Mapping

Map Variables to Systems

| Variable Name | Number of Systems | System1 Name | Pct1 | System2 Name | Pct1 | System2 Name | Pct1 |
|---|---|---|---|---|---|---|---|
| FLOW CFS | 0 | | 0 | | 0 | | 0 |
| Total N | 3 | NH4 | 10 | NO3 | 20 | ON | 70 |
| Total P | 2 | OPO4 | 15 | OP | 85 | | 0 |
| Var3 | 0 | | 0 | | 0 | | 0 |
| Var4 | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |
| DUMMY VARIAB | 0 | | 0 | | 0 | | 0 |

Number of Wasp Systems to be mapped to the Swmm Variable (max. 3)

**Figure 7. Mapping SWMM conduit IDs to WASP segments.**

## Model System Application—Lake Thonotosassa, Florida

### *Study Area Description*

Lake Thonotosassa is located in northeast Hillsborough County, Florida (Figure 8). The lake has a surface area of 813 acres, with a maximum depth of approximately 16 feet. It is tributary to the Hillsborough river system, a source of water supply for Tampa, and a part of the Tampa Bay ecosystem providing freshwater to the estuary.

The watershed is approximately 55 square miles and extends east to Plant City and south to Sydney (Figure 8). Elevation in the watershed ranges from 35 ft National Geodetic Vertical Datum (NGVD) along the shoreline of the lake to 145 ft in the eastern section of the catchment. The area in general has relatively mild slopes but is steeper on the eastern section when compared with the southern and western sections. This lake was chosen in part due to the relatively large database available as a result of recently completed diagnostic/feasibility studies (6).

### *Modeling*

Available data included topographic maps, land use, soils, rainfall, wind, solar radiation, water levels, and water quality. These data were utilized in the model setup and calibration processes. Modeling consisted of developing a database linkage from the GIS, watershed modeling with the SWMM model, and water-body modeling with RIVMOD and WASP4. The modeling scenarios are described below.

Digitized land use and soils data were obtained from the SWFWMD on magnetic tapes and downloaded to the Dames and Moore ARC/INFO system. Drainage divides that define subbasins were digitized as an additional overlay. These data provided the basis for developing the *.GDF file, which was linked with the SWMM model via the PRESWMM program package. These maps were directly output from the GIS. In addition, the GIS was used to provide aggregate maps for soils and land use.

The GIS identified 42 land uses at up to Level III for the watershed. SWMM is capable of utilizing five land uses in its watershed modeling. A decision was therefore made to aggregate land uses to provide five classes with similar characteristics. The classes selected were urban, agriculture, open, wetlands, and uplands. To maintain flexibility in redefining aggregates during the

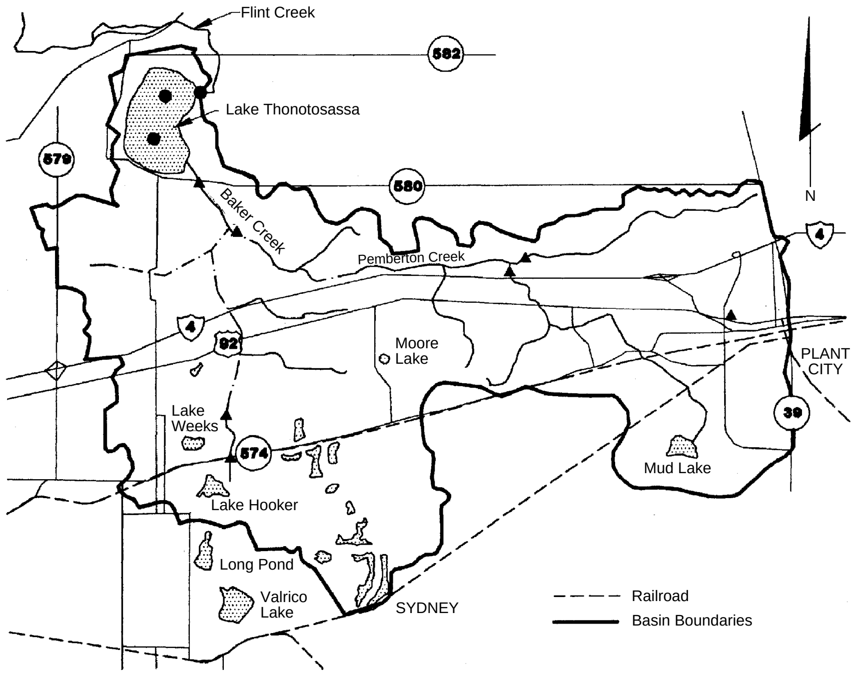


**Figure 8. Lake Thonotosassa location map.**

modeling process, the unaggregated GIS database served as model input to PRESWMM. PRESWMM then provided the aggregated land-use data for modeling purposes.

SCS soils data on the GIS are more detailed than required for modeling purposes. These data were aggregated in the GIS to provide mapping of hydrologic soil groups A, B, C, or D, as provided by the Hillsborough County soils map and document (7).

The SWMM model (RUNOFF block) was used to simulate both water quantity and water quality inflows to the lake. Before the input file was set up, the watershed was segmented into 34 subbasins. The subbasins were defined by examining topographic, land-use, and soils maps.

To set up SWMM, PRESWMM was used to create an input file consisting of information from the GIS system and user control input (UCI). The GIS system provided land-use and soils information, as previously discussed. These data served as input to PRESWMM, which created the input file for SWMM. In addition, UCIs were input into the PRESWMM interactive program. These UCIs include data on catchment slopes, overland Mannings roughness coefficient (n), evaporation, infiltration rates, basin widths, percent of directly connecting impervious area (DCIA), depression storage, channel slopes, channel lengths, channel geometry, and channel Mannings roughness coefficient (n). Channel basin linkages are also defined so that the model can route flows from the land segment to channels, and from channels to other channels.

After the model was set up, a data period was selected for calibration. The period was from June 11, 1991, to April 24, 1992, and was selected to coincide with available discharge measurement records. The model was calibrated by conducting a series of model runs, comparing simulated and measured data, and adjusting parameters.

The calibration was based primarily on data collected at two stations, LT-4 and LT-5. Station LT-5 is located on Pemberton Creek just upstream of the Baker Creek confluence, which represents 40 percent of the total watershed. The other calibration point is station LT-4, which covers 98 percent of the lake's watershed. The difference in flows between these stations is that contributed by Baker Creek draining the southern portion of the catchment. The final calibration plot for LT-4 is shown in Figure 9.

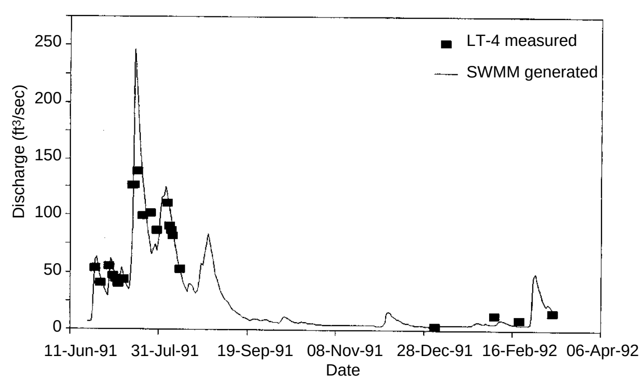


**Figure 9. Lake inflow calibration.**

The SWMM water quality setup used the same setup as for the water quantity except that coefficients that define buildup/washoff rates and rating curves were added to the routine. The calibration was performed by comparing water quality concentrations for measured and simulated total nitrogen and total phosphorus. The procedure was a sequence of model runs, comparing results, and adjusting parameters.

### *Water-Body Modeling*

Water and pollutant loading inflows generated by SWMM were used as input to the lake, and the lake water quality was simulated. The following two models were used: 1) RIVMOD was used to simulate the dynamics of the inflows, outflows, and change storage in the lake, and 2) EUTRO4 used the simulated hydrodynamics and relevant quality parameters to simulate the lake's water quality.

Sources of pollutants to the lake were identified, with emphasis on nutrient loading. An in-lake model was applied by utilizing ambient water quality data and flows and pollutant loadings from the watershed to model current in-lake processes. The model was calibrated for nitrogen, phosphorus, and chlorophyll-*a.* WASP4 was the lake model used in simulating the in-lake processes.

The lake and inlet channel was subdivided into 10 segments. Four of the segments were in the inlet channel (Baker Creek). These segments were included to allow some flexibility in modification, if necessary, of the nutrient input to the lake during the lake water quality calibration process. The lake had six segments; this was believed to be adequate considering that there were only two water quality data collection stations. The final segment represents the lake outflow point. The segmentation is shown in Figure 10.

The eutrophication water quality model (EUTRO4) was set up as a system of 10 water column segments (Figure 10) to coincide with the hydrodynamic setup. Model time step was one day, with simulation for all eight systems of the WASP4 Intermediate Eutrophication Kinetics package. The eight systems are ammonia, nitrate+nitrate, orthophosphate, chlorophyll-*a,* biochemical oxygen demand, dissolved oxygen, organic nitrogen, and organic phosphorus. Water column segments interact with each other both by advective flows and diffusive exchange.

The SWMM model generated loads of total nitrogen, total phosphorus, and biochemical oxygen demand (BOD). For water quality modeling, data on nitrate-nitrate nitrogen, organic nitrogen, ammonia nitrogen, orthophosphate, and organic phosphorus were required. These constituents were estimated by applying stoichiometric ratios obtained from the data collected during the extensive data collection period. Loads of

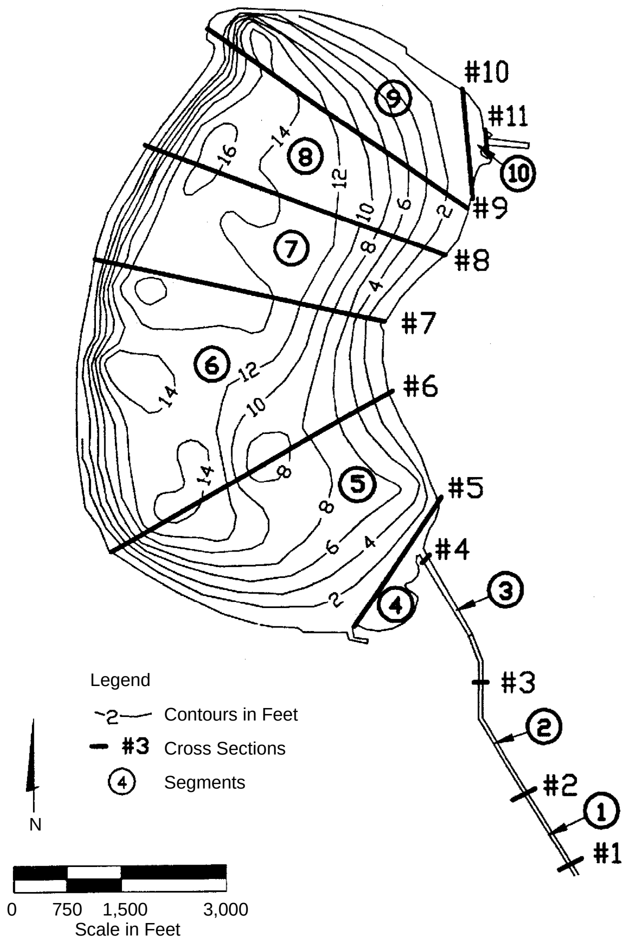


**Figure 10. Lake Thonotosassa modeling segmentation and bathymetric map.**

dissolved oxygen were also included in the model. These were obtained by applying monthly dissolved oxygen data to SWMM simulated flows.

Seven environmental parameters were included in the setup. The parameters defined values for salinity, segment temperature, ammonia flux, phosphate flux, and sediment oxygen demand. Salinity and temperature were derived from field measurements. Some of the constants associated with the environmental parameters were pointers used in combination with various time functions to define time series of water temperature, solar radiation, fraction daylight hours, and wind velocity. Time series of water temperature, solar radiation, and wind velocity were derived from the available data discussed above. Fraction of daylight hours was obtained from latitude-dependent information presented in Chow (8).

Initial constituent concentration was based on the measurements of June 26, 1991, and initial model time. Organic phosphorus was assumed to be the difference between total phosphorus and orthophosphate. It is recognized, however, that organic phosphorus may be overestimated because of particulate forms of inorganic phosphorus. Organic nitrogen was calculated from total Kjeldahl nitrogen and ammonia.

The model was set up with the constants required for eutrophication simulation. Values for these constants were derived primarily from the literature (9), although some field measurements were used as guidance to determine constants. These constants were primarily calibration factors.

Calibration was accomplished by adjusting constants within reasonable limits until a satisfactory fit between measured and simulated data was obtained (Figures 11 to 13). In some instances, although the model fit was by no means perfect, the model was considered calibrated within the constraints of the various estimates of inflows and environmental parameters. Constraints were associated with each of the eight systems in the eutrophication package: ammonia, nitrate-nitrate, orthophosphate, phytoplankton, BOD, dissolved oxygen, organic nitrogen, and organic phosphorus. Ammonia, nitrate-nitrate, and organic nitrogen are subsystems of the nitrogen cycle; orthophosphate and organic phosphorus are subsystems of the phosphorus cycle; and BOD and dissolved oxygen are subsystems of the dissolved oxygen balance. All systems interact.

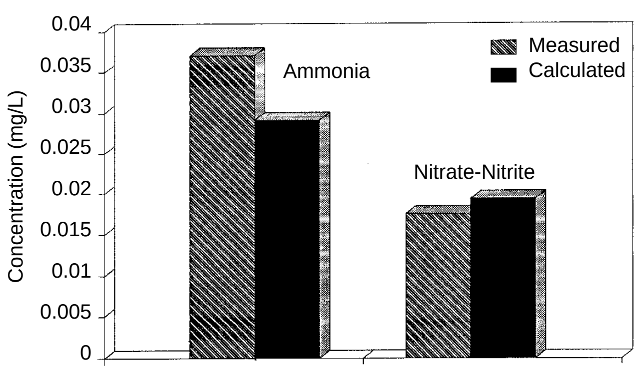


**Figure 11. Ammonia and nitrate-nitrite calibration, Lake Thonotosassa.**

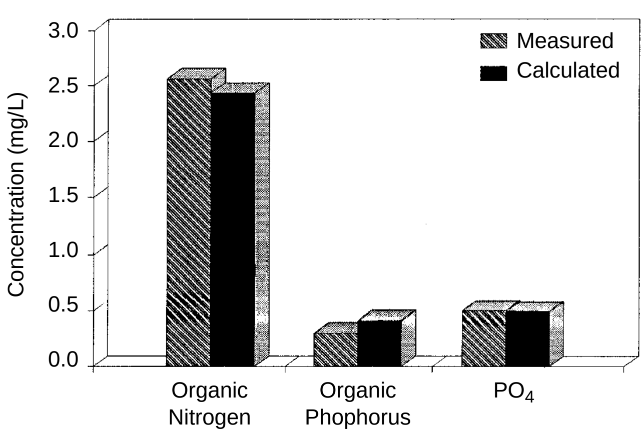


**Figure 12. Organic nitrogen, organic phosphorus, and $PO_4$ calibration, Lake Thonotosassa.**

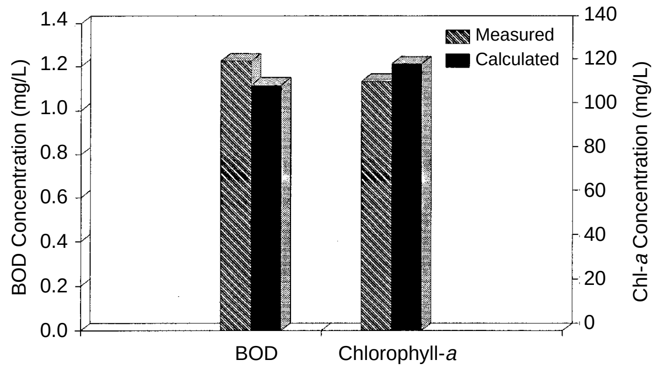


**Figure 13. BOD and chlorophyll-*a* calibration, Lake Thonotosassa.**

## Summary

The development and model components of the LWWM system and its user environment, SWISP, have been described. The LWWM has been applied to Lake Thonotosassa and its watershed. Water quantity and quality originating from the watershed were modeled as pollutant loading to the lake. In-lake processes were then simulated. Refinements are being made to the LWWM system in anticipation of project completion in September 1993. The resultant modeling system will be tested on two other systems, one a river flowing into an estuary (i.e., Little Manatee) and one a series of 19 interconnected lakes (i.e., the Winter Haven chain of lakes). It is anticipated that the resultant modeling system will become the district standard for eutrophication modeling of its surface water bodies. The final code and user's manual for SWISP will be public domain, and it is hoped that this modeling system will be used by other water resource managers in developing pollutant load reduction strategies for their water bodies.

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# AUTO_QI: An Urban Runoff Quality/Quantity Model With a GIS Interface

**Michael L. Terstriep and Ming T. Lee**
**Office of Spatial Data Analysis & Information,**
**Illinois State Water Survey, Champaign, Illinois**

## Abstract

This paper describes the development and application of the AUTO_QI model, which the authors developed at the Illinois State Water Survey in Champaign, Illinois. The paper includes background information on the Illinois Urban Drainage Area Simulator (ILLUDAS), on which AUTO_QI is hydrologically based. AUTO_QI stands for AUTOmated Quality-ILLUDAS. The model is automated in the sense that it includes an optional geographic information system (GIS) interface using ARC/INFO software. The Quality-ILLUDAS portion of the name indicates that the model simulates quality as well as quantity of runoff from an urban area.

AUTO_QI uses a continuous simulation of soil moisture to provide reliable estimates of antecedent moisture conditions for the simulation of selected runoff events. The soil moisture simulation requires a continuous precipitation record for the period of interest. The user may then specify some base rainfall above which the runoff volume and pollutant loading are then simulated for each event in the record. The resulting series of runoff volumes or pollutant loadings may then undergo statistical analysis. For each catchment in the study area, the user must provide soils and land cover information as well as buildup and washoff factors for each pollutant of interest. The model can simulate multiple drainage outfall points for a given rainfall record and group the results for different receiving waters. The user may incorporate specific best management practices (BMPs) into the simulation for comparison of loadings with and without BMPs. The paper also discusses use of the GIS interface including processing of remotely sensed data.

## Introduction

Models for simulation of urban runoff hydrographs such as the Illinois Urban Drainage Area Simulator (ILLUDAS) (1), Stormwater Management Model (SWMM) (2, 3), and Storage, Treatment, Overflow, Runoff Model (STORM) (4) have been used for some time. Their wide usage reflects their reliability for stormwater drainage design. Models that incorporate urban runoff water quality are available but are less common. The main reasons for this are:

- The water quality component is less reliable.
- The models require extensive input data.
- The models lack verification.

The relatively infrequent use of a water quality component is unfortunate because urban water quality modeling is a convenient tool for assessing pollutant loadings. Considering the high cost of monitoring and the lack of extensive data for using a statistical approach, the proper model with field data verification is a logical and feasible method for water quality assessments.

The principal investigators have developed an approach (5) that greatly reduces the cost of applying a deterministic model Q-ILLUDAS (6) to a relatively large area. This approach incorporates the ARC/INFO geographic information system (GIS) for data management. The savings comes from automation of input files. Readily available automated data include the U.S. Geological Survey (USGS) LUDA Level II land use data and the U.S. Census Bureau's DIME or TIGER/LINE file for population, housing, and street density. The streams, soils, and other data are also available in the Illinois and other state and federal GIS databases. This method is very effective for simulating regional urban runoff loadings that involve large databases and multiple outfalls. The model and GIS interface are known as AUTO_QI.

## Literature Review

Shaw (7) describes the special hydrologic problems of urban runoff as follows. The problem of estimating runoff from storm rainfall depends on the character of the catchment surface. The degree of urbanization (extent of impervious area) greatly affects the volume of runoff obtained from a given rainfall. Retention of rainfall by initial wetting of surfaces and absorption by vegetation and pervious areas reduces the amount of storm runoff. These surface conditions also affect the time distribution of the runoff. Computational methods used to obtain runoff from the rainfall should allow for the characteristics of the surface area to be drained. Thus, the first efforts in urban runoff modeling were to relate runoff from storm rainfall to the catchment characteristics.

The first stormwater sewer design method was the rational method by Kuchling (8). Sherman (9) introduced the unit hydrograph method. After the development of digital computers, early urban hydrologic models were developed, such as those by James (10), Papadakis and Preul (11), Terstriep and Stall (1), and McPherson and Schneider (12). One characteristic of urban runoff is that during the early minutes of a storm, urban runoff mainly derives from the impervious surfaces. Contributions from the pervious portion of the basin are highly variable and more difficult to define. Other research results may be found in Novotny and Chesters (13), Hann et al. (14), and Shaw (7).

Many conducted early urban runoff water quality modeling research, including Sartor and Boyd (15), Hydrologic Engineering Center (4), McPherson (16), Sutherland and McCuen (17), U.S. EPA (18-20), and Noel and Terstriep (6). Donigian and Huber (21) prepared a comprehensive review of modeling of nonpoint source water quality in urban and nonurban areas. Other reviews that consider surface runoff quality models include Feldman (22), Huber and Heaney (23), Kibler (24), Whipple et al. (25), Barnwel (26, 27), Huber (28, 29), Bedient and Huber (30), and Viessman et al. (31).

**Table 1. Urban Runoff Quality Model**

| Model | Authors | Year |
|---|---|---|
| QUAL-II | Hydrologic Engineering Center | 1975 |
| SWMM | Huber et al. | 1975 |
| STORM | Hydrologic Engineering Center | 1977 |
| MUNP | Sutherland and McCuen | 1978 |
| Q-ILLUDAS | Noel and Terstriep | 1982 |
| QQS | Geiger and Dorsh | 1980 |
| HSPF | Johanason et al. | 1980 |

Table 1 shows a partial list of urban water quality models.

For a detailed description of each of the models, the reader may review the respective references. This section will limit its discussion to the deposition and accumulation of pollutants on impervious surfaces and removal of solids from the street surface.

As reported by Sonnen (32), the state of the mathematical urban water quality model was fairly dismal a decade ago. Little has changed since then because the physical processes are so complex that they defy efforts to reduce them to mathematical statements. Consequently, semiempirical methods are often used.

### *Deposition and Accumulation of Pollutants on Impervious Surfaces*

As described by Novotny and Chesters (13), the primary sources of pollutants are wet and dry atmospheric deposition, litter, and traffic. Pollutants deposited on the surface during a dry period can be carried by wind and traffic and accumulate near the curb or median barrier. Thus, many studies report the street pollutant loading by unit length of curb.

The street refuse that runoff washes to storm sewers contains many contaminants. Significant amounts of organics, heavy metals, pesticides, and bacteria are commonly associated with street refuse. Factors that affect the pollutant accumulation rates are atmospheric fallout, wind, traffic, litter deposition, vegetation, and particle size distribution.

Pollutant accumulation in an urban area has a significant random component; thus, no mathematical model yields totally reliable results. Consequently, one common concept used is the storage-input-output schematic approach, which assumes that the amount of accumulated pollutants on a surface can be described as a simple mass balance formula:

$$dP/dt = A - r \qquad \text{(Eq. 1)}$$

where

A = pollutant accumulation rate (lb/day)
r = pollutant removal rate (lb/day)
P = amount of street refuse or dust/dirt present on the street (lb)
t = time in days

Integrating Equation 1, then:

$$P = A/r\,[1 - \exp(-rt)] + C \qquad \text{(Eq. 2)}$$

where

exp = exponential function
C = undefined constant

Using the empirical data from U.S. EPA (33), the parameters were defined for the Washington, DC, area as follows:

$$A = (ATMFL + LIT)\,(SW/2) + 1.15\ TD$$

$$r = 0.00116 \exp [0.0884 (TS + WS)]$$
$$C = 0$$

where

ATMFL = atmospheric fallout rate ($g/m^2$/day)
LIT = litter deposition rate ($g/m^2$/day)
SW = street width (m)
TD = traffic density (thousand axles/day)
TS = traffic speed (km/hr)
WS = wind speed (km/hr)

Sutherland and McCuen (17) made another attempt by developing a set of refuse accumulation functions using average daily traffic volume and pavement condition expressed by the present serviceability index (PSI). The results are a set of accumulation equations in terms of these input factors.

The accumulation of street refuse is the main pollution source in urban areas. Novotny and Chesters (13) reported on typical urban street refuse. Table 2 also presents findings from research on this topic.

The Chicago results indicate that multiple-family areas generate about three times more street dirt than single-family areas. The commercial and industrial areas generate about five and seven times more than the single-family areas.

The street refuse accumulation rate based on the eight American cities (15, 35) is two to four times higher than the Chicago dust/dirt accumulation rate. This reflects the wide variations in pollutant accumulation rates in existing measured field data for different cities.

## *Refuse Washoff by Surface Runoff*

When surface runoff occurs on impervious surfaces, the splashing effect of rain droplets and the drag forces of the flow put particles in motion. Sedimentation literature includes many hydraulic models that are potentially applicable to the problem of particle suspension and transport. Two models used frequently in urban runoff modeling are described below.

### Yalin Equation

Of numerous equations published in the literature, the Yalin equation (36) is probably one of the best for describing suspension and transport of particles by shallow flow typical for rills and street gutters. The equation has been reported in the following form:

$$p = 0.635\, s\, [1 - \ln (1 + as) / (as)] \qquad \text{(Eq. 3)}$$

where

p = particle transport per unit width of flow (g/m/sec)
$s = (Y/Ycr) - 1$
$a = 2.45 r_s^{-0.4} \sqrt{Ycr}$
ln = natural log function

The variables are defined as follows:

$$Y = \text{particle bed load tractive force} = \frac{\mu^*}{[(\rho_s - 1) g D]}$$

$\rho_s$ = particle density (g/c-cm$^3$)
Ycr = the critical tractive force at which sediment movement begins (newton/$m^2$)
D = particle diameter (m)
$\mu^*$ = sheer velocity (m/sec)
g = gravity acceleration (m/sec$^2$)

Based on Yalin's equation, Sutherland and McCuen (17) developed a washoff model. The model is based on the relationship between percentage removal of total solids in a particle range (0.001 to 1.0 mm) due to a total rainfall volume of 1/2 in. and correlation factor Kj such that:

$$TSj = Kj\, (TSi) \qquad \text{(Eq. 4)}$$

where

TSj = percentage removal of total solids in a particle range due to total rainfall volume j, measured in mm

**Table 2. Street Refuse Accumulation**

| | Solids Accumulation | | | |
|---|---|---|---|---|
| | Chicago (34) Dust and Dirt | | Eight American Cities (15, 35) Total Solids | |
| **Land Use** | **g/curb miles/day** | **lb/acre/day** | **g/curb miles/day** | **lb/acre/day** |
| Single family | 10.4 | 2.1[a] | 48 | 9.5[a] |
| Multiple family | 34.2 | 6.8[a] | 66 | 13.1[a] |
| Commercial | 49.1 | 9.7[a] | 69 | 13.7[a] |
| Industrial | 68.4 | 13.5[a] | 127 | 25.1[a] |

[a]The curb density in Chicago and eight American cities was assumed by the authors to be 90 m/acre.

Kj = factor relating TSj and TSi
TS = percentage removal of total solids in the particle range due to a total rainfall of 1/2 in.

**Sartor et al. Washoff Function**

The Sartor et al. washoff function is based on the first-order washoff function (15, 35):

$$dP/dt = - Ku\ r\ P \qquad \text{(Eq. 5)}$$

where

P = amount of solids remaining in pounds
t = time in days
Ku = constant depending on street surface characteristics (called urban washoff coefficient)
r = rainfall intensity (in./hr)

The constant Ku was found independent of particle size within the studied range of 10 to 1,000 µm. The integrated form of the equation can be expressed as:

$$P_t = P_o\ [1 - \exp\ (-Ku\ r\ t)] \qquad \text{(Eq. 6)}$$

where

$P_o$ = initial mass of solids in the curb storage
$P_t$ = mass of material removed by rain with duration t
exp = exponential function

In spite of the Sartor concept's highly empirical nature and arbitrarily chosen constants, many urban runoff models such as SWMM (2, 3) and STORM (4) have incorporated it.

## AUTO_QI Model

### *Model Overview*

AUTO_QI actually comprises three programs known as HYDRO, LOAD, and BMP. These programs run in series, each using output from the previous program as input along with additional information from the user. HYDRO performs a continuous simulation of soil moisture based on a daily and hourly rainfall record that the user provides. It also computes runoff volume for each event above some user-specified rainfall amount. LOAD uses these runoff volumes along with additional pollutant accumulation and washoff information to calculate pollutant loadings for each runoff event. The BMP program then reduces these loadings in accordance with user-specified best management practices (BMPs) and reports the results both with and without BMP conditions. The simulation process may be examined by looking at wet and dry periods.

### *Runoff*

Runoff may only occur during a "wet period," a day during which rainfall occurs. During these potential runoff periods, the model requires hourly rainfall amounts. The basin is assumed to have three types of area: directly connected paved area, supplemental paved area, and contributing grassed area. As the name implies, runoff from the directly connected paved area flows directly to the storm system. Runoff from the supplemental paved area flows first across the grassed area and is thus subjected to infiltration losses. The remainder of the basin is assumed to be grassed area, so all rain falling on this surface is also subjected to infiltration losses.

**Paved Area Runoff**

The model distinguishes between directly connected paved area and supplemental paved area. The losses from directly connected paved area consist of initial wetting and depression storage. These losses are combined and treated as an initial loss; they are subtracted from the beginning of the rainfall pattern. After subtracting these losses from the rainfall pattern, the remainder of the rainfall appears as effective rainfall and thereby as runoff from the paved area.

**Grassed Area Runoff**

Computation of grassed area runoff includes runoff from the supplemental paved area because both are subjected to infiltration. As in the case of paved area runoff, rainfall is the primary input for grassed area runoff calculations. The modifications that must change the rainfall pattern to grassed area runoff are much more complex than in the paved area case. The procedure followed here first adds in supplemental paved area runoff, then subtracts initial and infiltration losses.

In this model, rainfall on the supplemental paved area is simply distributed by linear weighting over the entire grassed area, thereby modifying the actual rainfall for grassed areas such that:

$$R' = R\ (1.0 + SPA/CGA) \qquad \text{(Eq. 7)}$$

where

R′ = effective rainfall on the grassed area
R = actual rainfall
SPA = supplemental paved area
CGA = contributing grassed area

In an urban basin, bluegrass turf most often covers the area that is not paved. When rain falls on this turf, there are two principal losses. The first is associated with depression storage and the second with infiltration into the soil. In this model, depression storage fills and maintains, and infiltration is satisfied before any runoff takes place. Depression storage is normally considered to be 0.20 in., but the model provides for this to be varied.

The dominant and far more complex loss of rainfall on grassed areas is caused by infiltration. The theoretical approach to evaluating infiltration rates uses the physical properties of the soil to estimate the water storage available in the soil mantle, and evaluates the role of this water storage as rain water infiltrates into and through the soil mantle. The original ILLUDAS manual provides details of water storage in soil and infiltration rates through soil. The following text offers only brief descriptions.

### Water Storage in Soil

The amount of water that the soil mantle can store depends on the total pore space available in the soil between the soil particles. This model divides the total water stored in the soil mantle into two principal parts. The first of these is gravitational water. This is the water that will drain out of soil by gravity. The second is evapotranspiration (ET) water. This is the water that plants can remove through evapotranspiration.

Soil moisture storage capacity varies with soil type and may be classed by hydrologic soil group. This model considers seven hydrologic soil groups. The U.S. Soil Conservation Service describes the hydrologic soil groups as follows:

A = low runoff potential and high infiltration rate (consists of sand and gravel)
AB = soil having properties between soil types A and B
B = moderate infiltration rate and moderately well drained
BC = soil having properties between soil types B and C
C = slow infiltration rate (may have a layer that impedes downward movement of water)
CD = soil having properties between soil types C and D
D = high runoff potential and very slow infiltration rate (consists of clays with a permanent high water table and high swelling potential)

Appendix B supplies default values of soil moisture storage capacity for different soil types. Users can change these values to suit their own experience. For further references, see Eagleson (37) and Richey (38).

### Infiltration Rate

Knowing the water storage available for infiltration within a soil mantle makes it possible to compute the infiltration rate at any time from the Horton equation, as given by Chow (39):

$$f = f_c + (f_0 - f_c)\exp(-kt) \qquad \text{(Eq. 8)}$$

where

$f_c$ = final infiltration rate (in./hr)
$f_0$ = initial infiltration rate (in./hr)
k = shape factor
t = time from start of rainfall (hr)
exp = exponential function

This equation is solved by the Newton-Raphson technique for given $f_c$ and $f_o$ values that depend on soil properties supplied by the user. A shape factor (k) of 2 was used to provide the shape best reflecting natural conditions.

The total amount of infiltration during a storm event depends on the total amount of soil moisture (ET water and gravitational water) in storage. The higher the amount of available soil moisture, the lower the amount of infiltration, and vice versa. This model distributes the total amount of infiltration among ET storage and gravitational storage in a preassigned 60:40 ratio. AUTO_QI continuously simulates soil moisture so that a reliable soil moisture is available at the beginning of any event.

During dry periods, the model operates on two different time steps: daily if there is no rainfall on the current day and hourly if there is rainfall at some time during the current day. During dry periods, depression storage and soil moisture depend on:

- Evaporation, at a user supplied rate, from depression storage.
- Infiltration from depression storage, with the infiltration volume separated in a 60:40 ratio into ET water and gravitational water.
- Evapotranspiration, at a user specified rate, from ET water storage.
- Percolation, at a constant rate $f_c$, from gravitational water storage.

### Spatial Distribution of Runoff Processes

The model assumes all of the wet period and dry period processes are spatially distributed, and simulates by the use of a triangular distribution. Figure 1(a) shows a distribution assumed to vary linearly from zero to twice

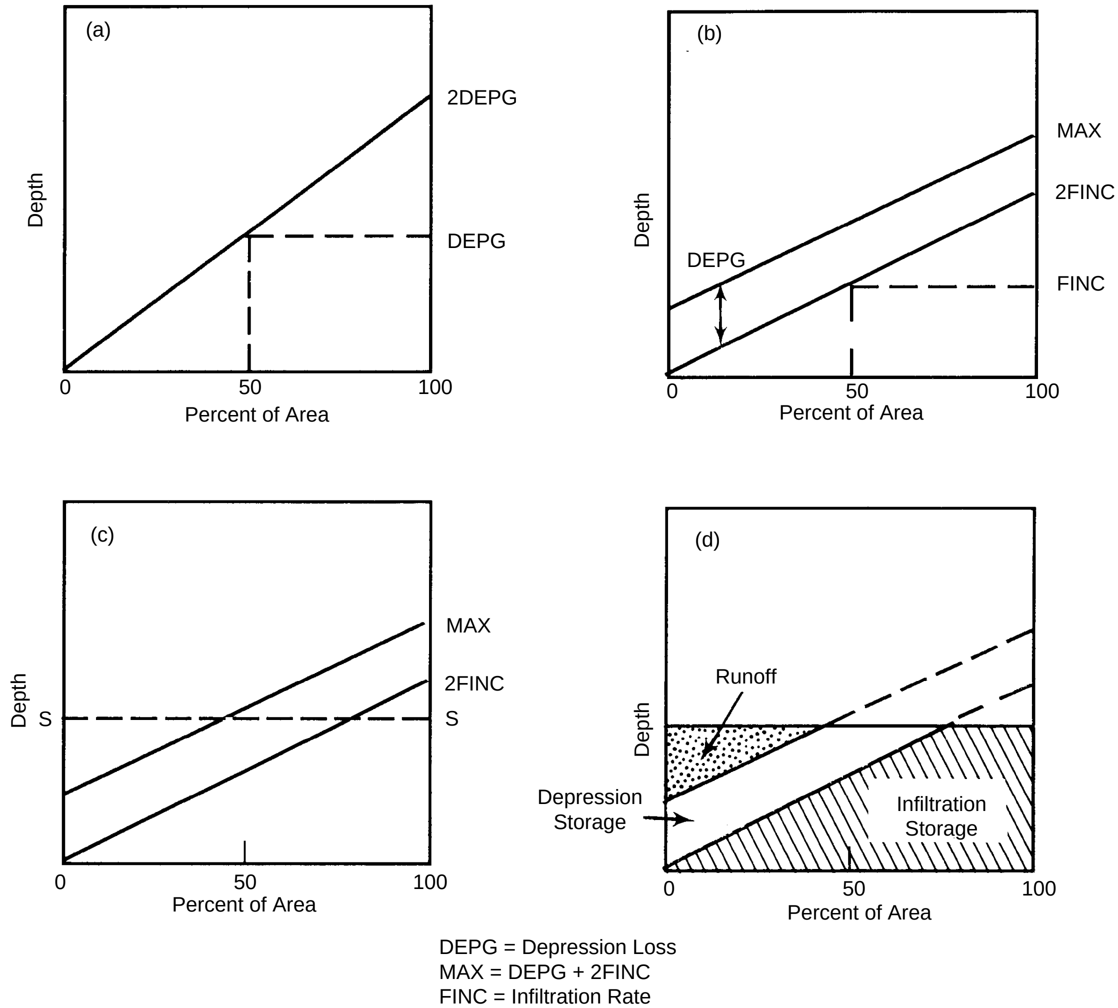


**Figure 1. Triangular spatial distribution of runoff.**

the user-specified mean value over the subcatchment area. DEPG, as an example, is the mean pervious depression storage. Figure 1(b) shows the concurrent processing of depression storage and infiltration potential. Although both filling of depression storage and infiltration are assumed to be spatially distributed, they are also assumed to be totally independent of one another physically. Depression storage may therefore have a uniform distribution with respect to infiltration potential.

The concurrent processing of infiltration and depression storage, Figures 1(c) and 1(d), assumes that infiltration potential varying from zero to 2FINC is satisfied for a particular level of supply, S, before considering depression storage. The supply rate S is defined as the sum of the rainfall and the uniformly distributed volume of depression storage at the start of the interval. The volume below S and between curves 2FINC and MAX represents the moisture supply to depression storage in the interval and is processed according to the above discussion of Figures 1(a) and 1(b). The volume remaining below S and above the curve bounded by MAX is the surface runoff volume for the hour.

## *Pollutant Generation*

After generating an effective hyetograph for both pervious and impervious areas, these rainfall depths are supplied as input to the program LOAD. LOAD then generates the washoff of different pollutants from the storm event. LOAD uses linear accumulation and exponential washoff equations. The user supplies the number of pollutants and associated characteristics such as daily accumulation rate and daily removal rate.

### Dry Periods

One form of mass balance formula in discrete form is the linear accumulation equation, which generates the antecedent pollutant load at the beginning of an event as follows:

$$P_t = Pt\text{-}1\ (1\text{-}r) + A \qquad \text{(Eq. 9)}$$

where

$P_{t-1}$ = initial load at time t-1

$P_t$ = load at time t
r = background removal rate
A = daily accumulation rate

**Wet Periods**

At the start of rainfall, the amount of a particular pollutant on a surface that produces runoff will be Po, in lb/acre. Assuming that the pounds of pollutant washed off in any time interval, dt, are proportional to the pounds remaining on the ground, P, the first order differential equation is:

$$-dP/dt = kP \quad \text{(Eq. 10)}$$

When integrated, this converts into the exponential washoff function for the removal of the surface loads as follows:

$$P_0 - P = P_0(1 - \exp(-kt)) \quad \text{(Eq. 11)}$$

where

$P_0 - P$ = washoff load (lb/acre)
k = proportionality constant
t = storm duration in hours

To determine k, the model uses the same assumption as the SWMM model. Therefore, k varies in direct proportion to the rate of runoff such that:

$$k = iB$$

where

i = runoff (in./hr)
B = constant

To determine B, it was assumed that a uniform runoff of 1/2 in./hr would wash away 90 percent of the pollutant from paved areas and 50 percent of the pollutant from grassed areas in 1 hour. That leads to a value for B of 4.6 for paved areas and 1.4 for grassed areas. These are default values that the user can modify.

To find the washoff load, apply each constituent's loading parameters to the buildup function to determine the initial load (by land use). Then apply the exponential washoff equation for impervious and pervious areas. The event mean concentration (EMC) is determined by dividing the total washoff loads by the runoff volume for each land use.

### *Best Management Practices*

BMPs are the measures implemented to reduce pollutants from source areas, or in streams and receiving waters. Many factors govern BMP pollutant removal ability. Schueler (40) outlined three primary interrelated factors:

- The removal mechanisms used.
- The fraction of the annual runoff volume that is efficiently treated.
- The nature of urban pollutants being removed.

The AUTO_QI model does not model specific BMP processes but represents the effectiveness of BMPs by a removal efficiency factor. The model can handle one or more BMPs in a catchment or portion of a catchment. The pollutant removal factor may be inferred from field performance monitoring, laboratory experiments, modeling analyses, or theoretical considerations. Most model users, however, must rely on literature values as a starting point.

The particulate related pollutants, such as sediment and lead, are relatively easy to remove by common removal mechanisms, such as settling. Soluble pollutants, such as nutrients, are much more difficult to remove. The settling mechanism has little or no effect on these pollutants. Therefore, biological mechanisms, such as uptake by bacteria, algae, rooted aquatic plants, or terrestrial vegetation, are often used. A detailed description of individual BMPs can be found in Schueler (40) and Novotny and Chesters (13).

The model allows users to test the potential enhancement of water quality by implementing one or more BMPs in a catchment or group of catchments. The user specifies what portion, in percent, of a catchment the desired BMPs will affect and the removal efficiency of the BMPs. The model output lists the load and EMC without BMPs, followed by the load and EMC expected with BMPs. The user may apply this same procedure to reflect existing conditions if one or more BMPs are already in place.

## Data Preparation

### *Interfacing the GIS Database and AUTO_QI*

Urban runoff quantity and quality are highly dependent on the land use and hydrologic soil type. To tabulate the land use/soil complex for a large basin is a time-consuming process. To simplify the data collecting process, an optional ARC Macro Language (AML) program was developed to retrieve the land use/soil layers in a format suitable for model input.

The AML includes a menu-driven data review feature with two windows on the screen. The right window displays an index map of the whole drainage basin and the subbasin boundaries. The user can select a subbasin and display the land use, soil layers, streets, and storm sewers. If the user wants the land-use input file of a specific subbasin, the AML retrieves the attribute data and generates an ASCII file for the model input.

### *AML Programs*

The AML programs link and provide the user interface between the GIS, which runs on a PRIME, and the AUTO_QI program, which runs on a PC. These programs process the data that AUTO_QI uses and also enable the user to view the graphic data at the subbasin level via a menu. The programs should be used with ESRI's ARC/INFO software on a PRIME computer and are grouped into two functions: the preprocessor programs and the menu system programs. PREPROCESSORLANDSOIL.AML, PREPROCESSORBMP.AML, and RUNIT.AML are the names of the three main programs.

PREPROCESSORLANDSOIL.AML uses the soil, land use, and BMP coverages to create a soil/land-use file for input to the AUTO_QI model. PREPROCESSORBMP.AML uses land-use and BMP coverages to create BMP application files for the AUTO_QI model. RUNIT.AML accesses the ARC/INFO menu system to view the coverages and INFO data. This menu also allows the user to choose and view individual subbasins and their data layers.

### *GIS Database Layers*

#### Soil Layer

In 1985, funding from the Illinois Department of Mines and Minerals (IDMM) allowed for the digitization of the statewide "General Soil Map of Illinois" for the Illinois GIS system. This map contains 57 general soil associations in Illinois. The attribute data include the soil surface color, surface code, and the hydrologic class (well drained, moderately well drained, somewhat well drained, and poorly drained). The AUTO_QI model needs this hydrologic soil classification for hydrologic modeling. The source map scale for the soil associations is 1:500,000.

#### Land Use Layer

The statewide land-use maps are available from the U.S. Geographical Survey LUDA digital database (41). The land uses are classified based on LUDA Level II, which contains 37 land-use categories (Appendix D). Digital Landsat image data or scanning aerial photographs have updated land-use/cover information (42-44). The Illinois State Water Survey has developed image analysis capability using the ERDAS image processing package (45). The results of a classified land use can easily be transferred to the ARC/INFO system.

#### Street Layer (DIME file/TIGER/LINE file)

Either the 1980 DIME file or the 1990 TIGER/LINE file, which were created by the U.S. Census Bureau, can provide the street coverage. The DIME and TIGER/LINE files comprise street segment records. A segment is defined as the length of a street feature between two distinct vertices or nodes. Other features are political boundaries and topologic features (e.g., rivers, shorelines, canals, railroads, airports). Additional demographic information is also available in the attribute data. This includes state, county, and standard metropolitan statistical area codes, aggregate family income, aggregate rental cost for occupied dwelling units, and numerous other demographic statistics. The data can be plotted by census tract. The source map scale is 1:100,000. The street layer is valuable for estimating the pollutant accumulation rate and the imperviousness of the drainage basin.

### *Sewer Network*

The database may also include an automated storm sewer network. The AML menu system provides for this coverage. The coverage is not required by the AML, however, and is not needed by AUTO_QI.

## Model Verification

### *Overview*

Due to the lack of observed data in the Lake Calumet area, the AUTO_QI model was verified by using the Boneyard Creek Basin in Champaign-Urbana, Illinois. The USGS has continuously gauged this station since 1948. The watershed area was reduced from 4.7 to 3.6 square miles in 1960 by a diversion. The basin contains a portion of Urbana, the commercial center of Champaign, and the University of Illinois campus. The central business district of Champaign makes up 7.5 percent of the drainage area and is nearly 100 percent impervious. Other city properties, including predominantly residential along with some commercial and light industrial, constitute an additional 81.2 percent of the basin. The remaining 11.3 percent of the basin is in parks, open space, and other land-use classes. Measurements have found the basin to be approximately 44 percent total paved area, which includes approximately 24 percent of direct connected paved area, 13 percent of supplemental paved area, and 7 percent of nonconnected paved area. The soils of the basin are predominantly Flanigan silt loam of hydrologic class B (8).

### *Runoff Simulation*

For runoff simulation, rainfall data for 3 years were chosen. These years represent low (25 percent), average (50 percent), and high (75 percent) annual exceedence of rainfall. Table 3 displays these data.

Land uses in the basin were simplified into two categories. Table 4 lists the land-use parameters for these categories which were used to verify the model.

**Table 3. Selected Years and Total Annual Rainfall**

| Year | Total Rainfall (in.) | Chance of Exceedence (percent) | Comments |
|---|---|---|---|
| 1959 | 35.94 | 50 | Average year |
| 1976 | 32.63 | 75 | Dry year |
| 1977 | 42.44 | 25 | Wet year |

**Table 4. Land-Use Parameters**

| Land Use | USGS Land Use Level 2 Code | % PA | % SPA | DEPI (in.) | DEPG (in.) |
|---|---|---|---|---|---|
| Residential | 11 | 15 | 20 | 0.1 | 0.1 |
| Commercial | 12 | 90 | 5 | 0.1 | 0.1 |

% PA = paved area in percent
% SPA = supplemental paved area in percent
DEPI = impervious depression storage depth
DEPG = pervious depression storage depth

## Results of Runoff Simulation

The events selected allowed the actual event runoff volume to be distinguished with reasonable confidence from the continuous runoff data. Table 5 presents the actual events for the "average year" of 1959.

Figure 2 shows that AUTO-QI does an acceptable job of reproducing runoff volumes for dry, average, and wet years. The simulated runoff/rainfall ratio for these 3 years is approximately 20 percent, which is consistent with the observed data and with what has been found previously (1).

## *Water Quality Simulation*

Water quality data for Boneyard Creek were available for eight events in 1982 from a study by Bender et al. (46). Simulated water quality data were compared with those 1982 data.

### Water Quality Parameters

Table 6 tabulates the pollutant accumulation/decay parameters required by the model and used in this study.

The accumulation rate and removal rate were selected based on typical Midwest urban runoff basins. No attempt was made to adjust these parameters to fit the observed data.

Table 7 tabulates the comparisons between simulated washoff and actual washoff of total suspended solids (TSS), phosphorus (P), and lead (Pb). The results of this verification are disappointing. They demonstrate, however, the problems of water quality simulation without verification and calibration data. The buildup and washoff factors in the model could be adjusted to "calibrate" the model to this data set and produce better results, but that was not the intent here.

**Table 6. Water Quality Parameters**

| | ARi (lb/acre/day) | ARp (lb/acre/day) | RRi (%) | RRp (%) |
|---|---|---|---|---|
| *For residential land use:* | | | | |
| Suspended solids | 7.6300 | 3.9900 | 4.50 | 4.50 |
| Phosphorus | 0.0138 | 0.0070 | 6.00 | 5.00 |
| Lead | 0.0100 | 0.0053 | 6.00 | 5.00 |
| *For commercial land use:* | | | | |
| Suspended solids | 9.5500 | 5.5500 | 3.00 | 4.50 |
| Phosphorus | 0.0100 | 0.0053 | 4.50 | 4.50 |
| Lead | 0.0110 | 0.0060 | 6.00 | 5.00 |

ARi = Accumulation rate for impervious area
ARp = Accumulation rate for pervious area
RRi = Removal rate for impervious area
RR = Removal rate for pervious area

**Table 5. Summary of Runoff Simulation for Selected Events in 1959**

| Date | Dry Days | Rainfall (in.) | Event Duration (hr) | Observed Runoff (in.) | Simulated Runoff (in.) | Simulated Grass Runoff (%) |
|---|---|---|---|---|---|---|
| 7/23/59 | 3.21 | 0.51 | 6.00 | 0.07 | 0.08 | 3 |
| 7/27/59 | 3.17 | 0.80 | 5.00 | 0.15 | 0.16 | 4 |
| 8/29/59 | 6.00 | 0.23 | 5.00 | 0.02 | 0.03 | 3 |
| 9/01/59 | 2.63 | 0.39 | 6.00 | 0.035 | 0.07 | 1 |
| 9/09/59 | 8.00 | 0.18 | 2.00 | 0.024 | 0.02 | 2 |
| 10/10/59 | 3.63 | 2.52 | 9.00 | 0.51 | 0.60 | 7 |
| 11/04/59 | 0.08 | 0.82 | 8.00 | 0.185 | 0.19 | 4 |
| 11/13/59 | 0.13 | 1.39 | 23.00 | 0.32 | 0.31 | 2 |
| 12/10/59 | 5.67 | 0.68 | 15.00 | 0.106 | 0.11 | 1 |

## Summary

A new comprehensive computer package was developed on the basis of two proven models for urban water quantity/quality assessment, ILLUDAS and Q-ILLUDAS. The package consists of three main parts:

- Water quantity/quality model, called AUTO_QI.
- A convenient menu system called QIMENU for preparing and editing inputs, viewing the outputs, running the model, and assisting users.
- A GIS interface called RUNIT, and other GIS processing programs.

The AUTO_QI model, which provides continuous simulation, consists of three main components: HYDRO, LOAD, and BMP. HYDRO uses a runoff/soil moisture accounting procedure, pervious and impervious depression storage, interception, Horton infiltration curves, and water storage in the soils to generate runoff volumes for each event in the record. LOAD is the water quality simulator that uses the output from HYDRO along with the pollutant accumulation and exponent washoff functions to generate loads and EMCs. BMP is the best management practices simulator that handles numerous separate or overlapping BMPs and produces the model output. The user may simulate the impacts of pollution reduction at multiple stormwater outfall points. The results can be viewed at one outfall point or multiple outfall points.

QIMENU aids users with preparation of input files, selection of parameters, running the model, testing the BMPs, and viewing the output.

The GIS interface uses the AML and automates the generation of the major input files for AUTO_QI. It also provides the user with a menu-driven program to review GIS coverages on the screen.

The model was verified by using data from the Boneyard Creek drainage basin in Urbana, Illinois. The three sets of rainfall data selected represent wet, average, and dry years. The input data consist of daily and hourly rainfalls, percent impervious and supplemental paved areas, depression storage, initial and final infiltration rates, gravitational and evapotranspiration soil storage, pollution accumulation and removal rate, and washoff factor. When comparing the outputs with the observed data for the Boneyard Creek basin, the results indicated that the model performed well for runoff volume. The simulations of pollutant loadings using the uncalibrated model were poor and indicate the need for further testing and calibration.

## Acknowledgments

This research was funded by Region 5 Water Division, Watershed Management Unit, EPA, Chicago, Illinois, and the Great Lakes National Program Office, EPA, Washington, DC. The EPA Project Officer was Thomas E. Davenport.

The principal investigators of this report were Michael L. Terstriep and Ming T. Lee. Thomas Davenport, EPA Regional Nonpoint Source Coordinator, reviewed the early versions of this report and provided a number of helpful comments and suggestions. Douglas Noel developed the program for the original Q-ILLUDAS model, consulted on this project, and provided a general outline for the revised computer program. M. Razeur Rahman wrote the LOAD and BMP portion of the model. Evan P. Mills wrote the menu-driven program QIMENU for handling the inputs and outputs. Amelia V. Greene wrote the AML program for the GIS interface. John Brother prepared the graphical work.

**Table 7. Washoff Load Simulation for Selected Events of 1982**

| | | | TSS | | Phosphorus | | Lead | |
|---|---|---|---|---|---|---|---|---|
| Date | Rainfall (in.) | Runoff (in.) | Sim. (lb) | Obs. (lb) | Sim. (lb) | Obs. (lb) | Sim. (lb) | Obs. (lb) |
| 3/19/82 | 0.52 | 0.08 | 12,312 | 18,777 | 18 | 18 | 15 | 11 |
| 4/02/82 | 0.66 | 0.11 | 6,954 | 89,179 | 10 | 75 | 8 | 77 |
| 4/15/82 | 0.12 | 0.01 | 2,388 | 3,332 | 10 | 7 | 3 | 4 |
| 4/16/82 | 0.60 | 0.10 | 19,549 | 52,087 | 28 | 46 | 23 | 48 |
| 5/15/82 | 0.43 | 0.07 | 25,409 | 25,857 | 36 | 29 | 29 | 15 |
| 6/15/82 | 1.17 | 0.21 | 3,302 | 30,969 | 5 | 48 | 5 | 35 |
| 6/28/82 | 0.98 | 0.16 | 29,808 | 22,931 | 43 | 31 | 35 | 5 |
| 7/18/82 | 1.14 | 0.30 | 5,070 | 19,001 | 8 | 26 | 6 | 11 |

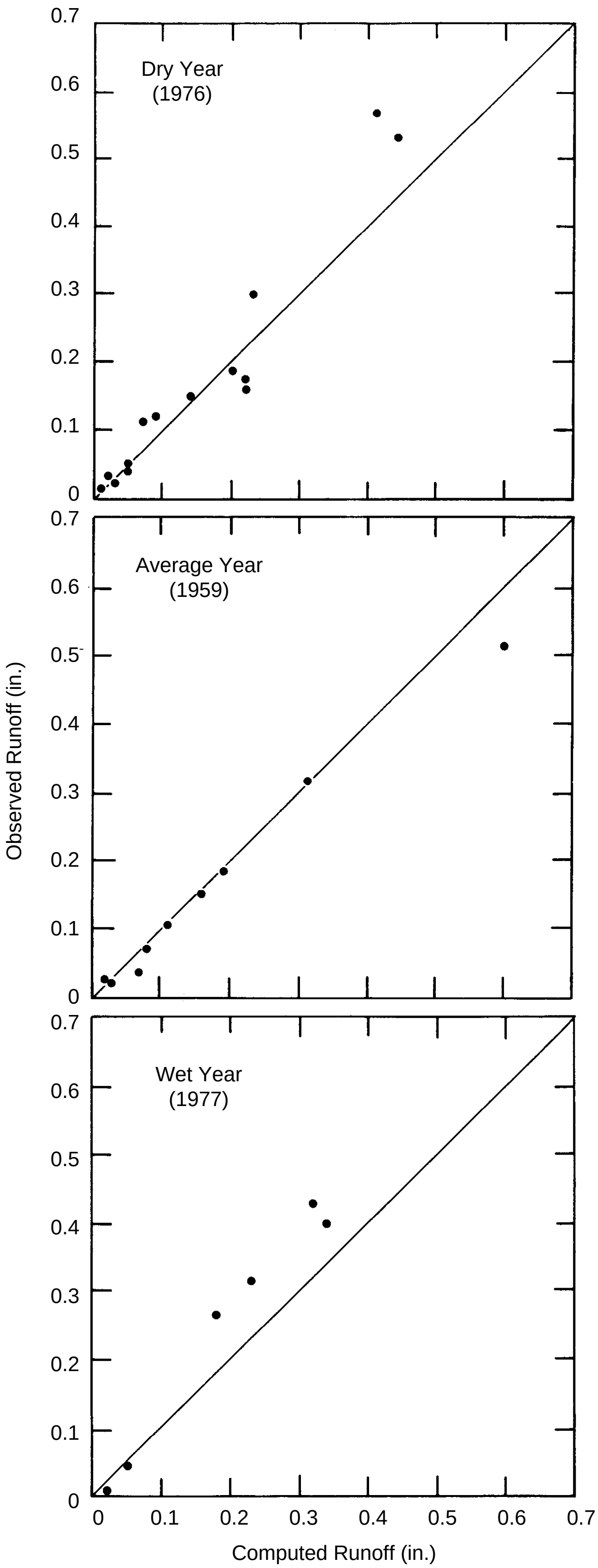


**Figure 2. Comparison of observed and computed event runoff volumes in Boneyard Creek basin, Champaign-Urbana, Illinois.**

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# *Source Loading and Management Model (SLAMM)*

**Robert Pitt**
**Department of Civil Engineering, University of Alabama at Birmingham, Birmingham, Alabama**
**John Voorhees**
**Johnson Johnson & Roy/Inc., Madison, Wisconsin**

## Introduction

The Source Loading and Management Model (SLAMM) was developed to more efficiently evaluate stormwater control practices. It soon became evident that to accurately evaluate the effectiveness of stormwater controls at an outfall, the sources of the pollutants, or problem water flows, must be known. SLAMM has evolved to include a variety of source area and end-of-pipe controls and the ability to predict the concentrations and loadings of many different pollutants from many potential source areas. SLAMM calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls. It was designed to give relatively simple estimates (pollutant mass discharges and control measure effects) for a very large variety of potential conditions.

SLAMM was developed primarily as a planning level tool, for example, to generate information needed to make planning level decisions while not generating or requiring superfluous information. Its primary capabilities include predicting flow and pollutant discharges that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices. Control practices evaluated by SLAMM include detention ponds, infiltration devices, porous pavements, grass swales, catchbasin cleaning, and street cleaning. These controls can be evaluated in many combinations and at many source areas as well as the outfall location. SLAMM also predicts the relative contributions of different source areas (e.g., roofs, streets, parking areas, landscaped areas, undeveloped areas) for each land use investigated. As an aid in designing urban drainage systems, SLAMM also calculates U.S. Department of Agriculture Soil Conservation Service (SCS) curve numbers (CNs) that reflect specific development and control characteristics. These CNs can then be used in conjunction with available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls.

SLAMM is normally used to predict source area contributions and outfall discharges, but SLAMM (1) has also been used in conjunction with a receiving water model (HSPF) to examine the ultimate effects of urban runoff.

The development of SLAMM began in the mid-1970s, primarily as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the U.S. Environmental Protection Agency's (EPA's) Storm and Combined Sewer Pollution Control Program (2-4). Much of the information contained in SLAMM was obtained during EPA's Nationwide Urban Runoff Program (NURP) (5), especially the early Alameda County, California (6), and the Bellevue, Washington (7) projects. The completion of the model was made possible by the remainder of the NURP projects and additional field studies and programming support sponsored by the Ontario Ministry of the Environment (8), the Wisconsin Department of Natural Resources (9), and EPA Region 5 (this report). Early users of SLAMM included the Ontario Ministry of the Environment's Toronto Area Watershed Management Strategy (TAWMS) study (8) and the Wisconsin Department of Natural Resources' Priority Watershed Program (9). SLAMM can now be effectively used as a tool to enable watershed planners to obtain a better understanding of the effectiveness of different control practice programs.

A logical approach to stormwater management requires knowledge of the problems that are to be solved, the sources of the problem pollutants, and the effectiveness of stormwater management practices that can control the problem pollutants at their sources and at outfalls. SLAMM is designed to provide information on the last two aspects of this approach.

## Stormwater Problems

Before stormwater control programs can be selected and evaluated, it is necessary to understand the stormwater problems in local receiving waters. Table 1 lists typical receiving water problems associated with both the long-term accumulation of pollutants and the short-term (event-related) buildup of pollutants. Many of these problems have been commonly found in urban receiving waters in many areas of the United States (10). Because these problems are so diverse, an equally wide variety of individual stormwater controls must usually be used together. Unfortunately, combinations of controls are difficult to analyze using conventional stormwater models or the results of monitoring activities. SLAMM was developed to effectively examine control practices and land uses that may affect these receiving water problems.

**Table 1. Typical Receiving Water Problems**

| | |
|---|---|
| **Long-Term Problems Associated With Accumulations of Pollutants** | • Sedimentation in stormwater conveyance systems and in receiving waters.<br>• Nuisance algae growths from nutrient discharges.<br>• Inedible fish, undrinkable water, and shifts to less sensitive aquatic organisms caused by toxic heavy metals and organics. |
| **Short-Term Problems Associated With High Pollutant Concentrations or Frequent High Flows (Event Related)** | • Swimming beach closures from pathogenic microorganisms.<br>• Water quality violations.<br>• Property damage from increased flooding and drainage system failures.<br>• Habitat destruction caused by frequent high flow rates (e.g., bed scour, bank erosion, flushing of organisms downstream). |

## SLAMM Computational Processes

Figure 1 illustrates the development characteristics that affect stormwater quality and quantity. This figure shows a variety of drainage systems, from concrete curb and gutters to grass swales, along with directly connected roof drainage systems and drainage systems that drain to pervious areas. “Development characteristics” define the magnitude of these drainage efficiency attributes, along with the areas associated with each surface type (e.g., road surfaces, roofs, landscaped areas). The use of SLAMM shows that these characteristics greatly affect runoff quality and quantity. Land use alone is usually not sufficient to describe these characteristics. Drainage type (curbs and gutters or grass swales) and roof connections are probably the most important attributes affecting runoff quantity and quality. These attributes are not directly related to land use, but some trends are obvious; most roofs in strip commercial and shopping center areas are directly connected, and the roadside is most likely drained by curbs and gutters, for example. Different land uses, of course, are also associated with different levels of pollutant generation. For example, industrial areas usually have the greatest pollutant accumulations.

Figure 2 shows how SLAMM considers a variety of pollutant and flow routings that may occur in urban areas. SLAMM routes material from unconnected sources directly to the drainage system or to adjacent directly connected or pervious areas, which in turn drain to the collection system. Each of these areas has pollutant deposition mechanisms in addition to removal mechanisms associated with them. As an example, unconnected sources, which may include rooftops draining to pervious areas or bare ground and landscaped areas, are affected by regional air pollutant deposition (from point source emissions or from fugitive dust) and other sources that would affect all surfaces. Pollutant losses from these unconnected sources are caused by wind removal and rain runoff washoff, which flows directly to the drainage system or to adjacent areas. The drainage system may include curbs and gutters, where there is limited deposition, and catch basins and grass swales, which may remove substantial participates that are transported in the drainage system. Directly connected impervious areas include paved surfaces that drain directly to the drainage system. These source areas are also affected by regional pollutant deposition, in addition to wind removal and controlled removal processes, such as street cleaning. Onsite storage is also important on paved surfaces because of the large amount of participate pollutants that are not washed off, blown off, or removed by direct cleaning (2, 4, 6).

Figure 3 shows how SLAMM proceeds through the major calculations. There is a double set of nested loops in the analyses where runoff volume and suspended solids (particulate residue) are calculated for each source area and then for each rain. These calculations consider the effects of each source area control, in addition to the runoff pattern between areas. Suspended solids washoff and runoff volume from each individual area for each rain are summed for the entire drainage system. The effects of the drainage system controls (catch basins or grass swales, for example) are then calculated. Finally, the effects of the outfall controls are calculated.

SLAMM uses the water volume and suspended solids concentrations at the outfall to calculate the other pollutant concentrations and loadings. SLAMM keeps track of the portion of the total outfall suspended solids loading and runoff volume that originated from each source area. The suspended solids fractions are then used to develop weighted loading factors associated with each pollutant. In a similar manner, dissolved pollutant concentrations and loadings are calculated based on the

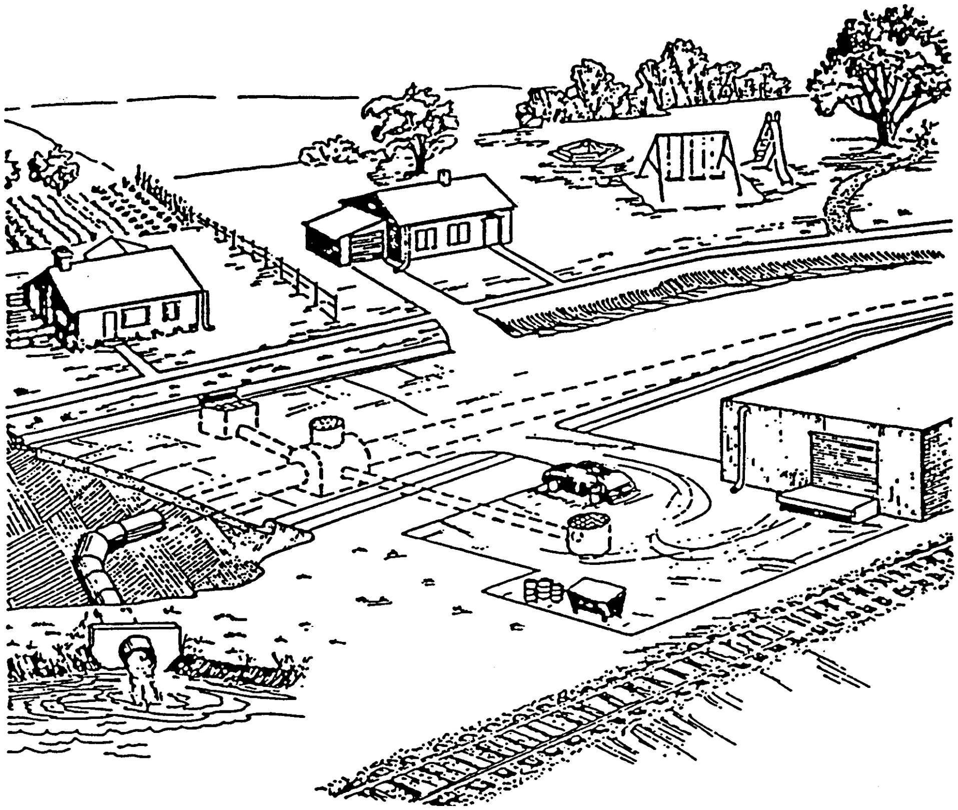

Figure 1. Urban runoff source areas and drainage alternatives (9).

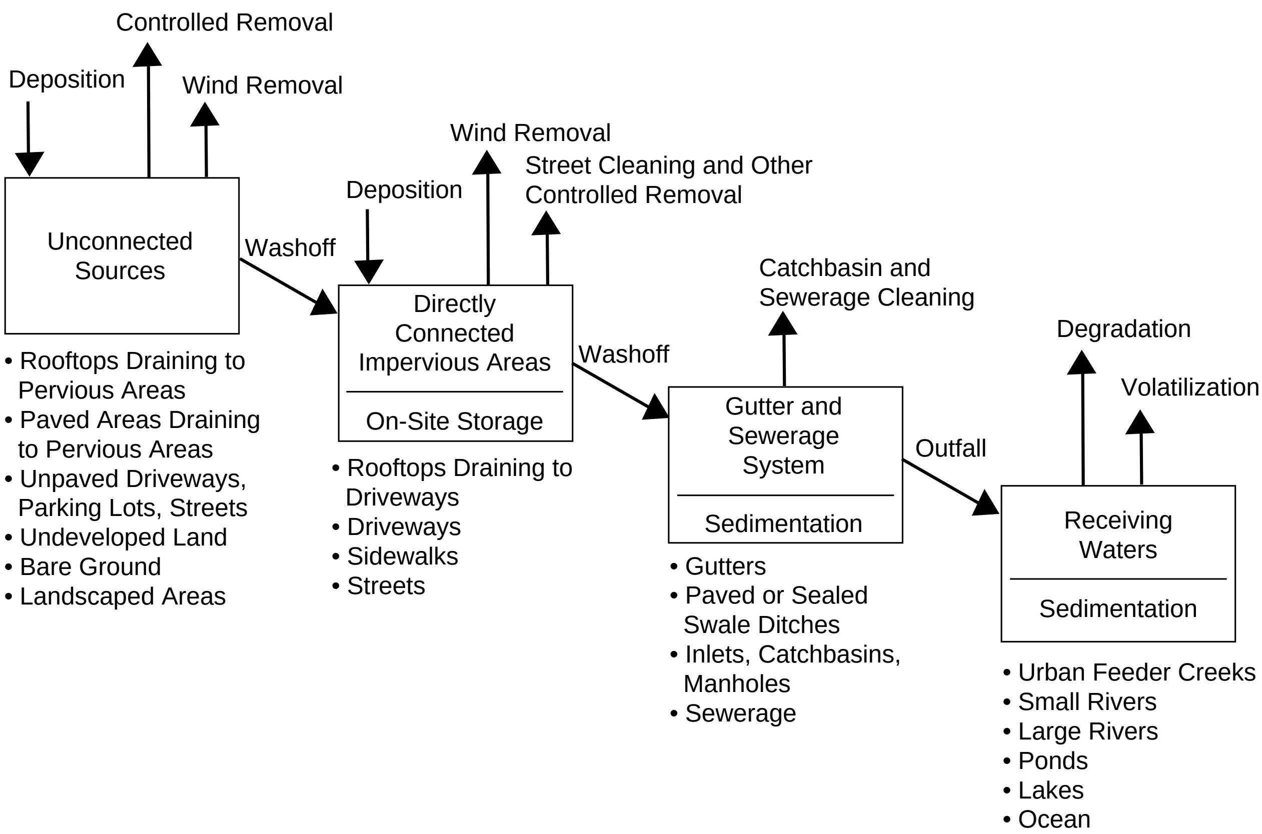


Figure 2. Pollutant deposition and removal at source areas (9).

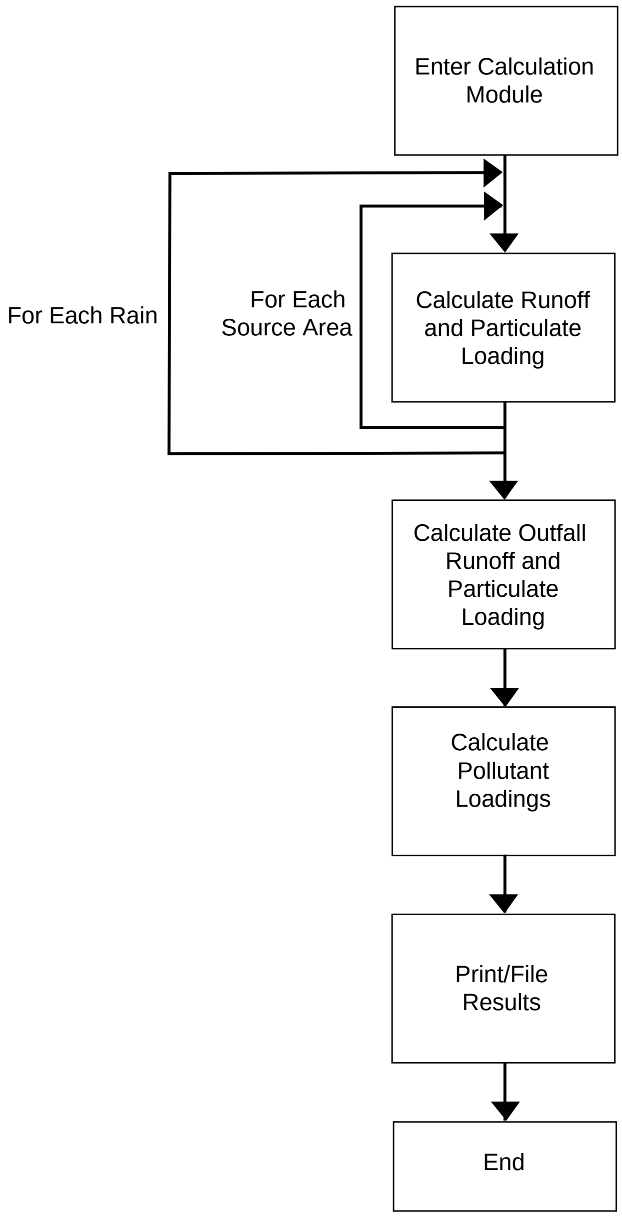


**Figure 3. SLAMM calculation flow chart.**

percentage of water volume that originates from each of the source areas within the drainage system.

SLAMM predicts urban runoff discharge parameters (total storm runoff flow volume, flow-weighted pollutant concentrations, and total storm pollutant yields) for many individual storms and for the complete study period. It has built-in Monte Carlo sampling procedures to consider many of the uncertainties common in model input values. This enables the model output to be expressed in probabilistic terms that represent the likely range of results expected.

## Unique Aspects of SLAMM

SLAMM is unique in many aspects. One of the most important aspects is its ability to consider many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains. Another is its ability to accurately describe a drainage area in sufficient detail for water quality investigations without requiring a great deal of superfluous information that field studies have shown to be of little value in accurately predicting discharge results. SLAMM also applies stochastic analysis procedures to represent actual uncertainty in model input parameters to better predict the actual range of outfall conditions (especially pollutant concentrations). The main reason SLAMM was developed, however, was because of problem areas in many existing urban runoff models. The following paragraphs briefly describe small storm hydrology and particulate washoff, the most significant of these problem areas.

### *Small Storm Hydrology*

One of the major problems with conventional stormwater models concerns runoff volume estimates associated with small storms. Figures 4 and 5 show the importance of common small storms when considering total annual pollutant discharges. Figure 4 shows the accumulative rain count and the associated accumulative runoff volume for a medium density residential area in Milwaukee, Wisconsin, based on 1983 monitored data (11). This figure shows that the median rain, by count, was about 0.3 in., while the rain associated with the median runoff quantity is about 0.75 in. Therefore, more than half of the runoff from this common medium density residential area was associated with rain events that were smaller that 0.75 in. The 1983 rains (which were monitored during the Milwaukee NURP project) included several very large storms, which are also shown on Figure 4. These

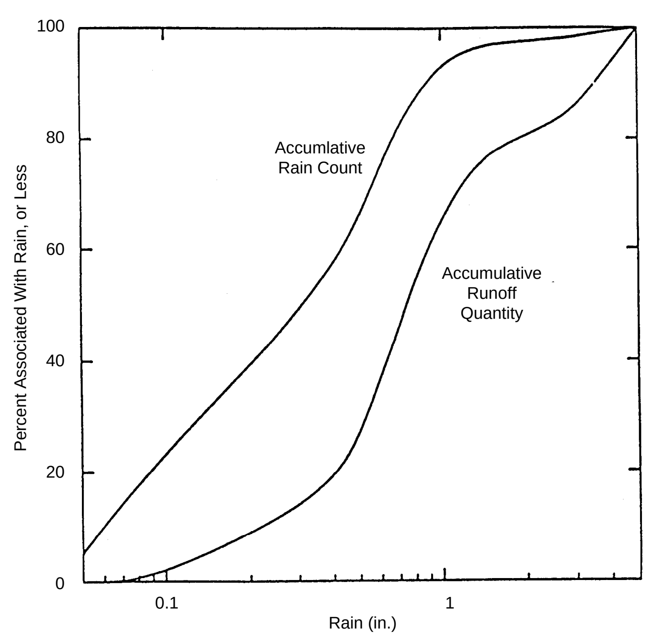


**Figure 4. Milwaukee rain and runoff distributions (medium-density residential area).**

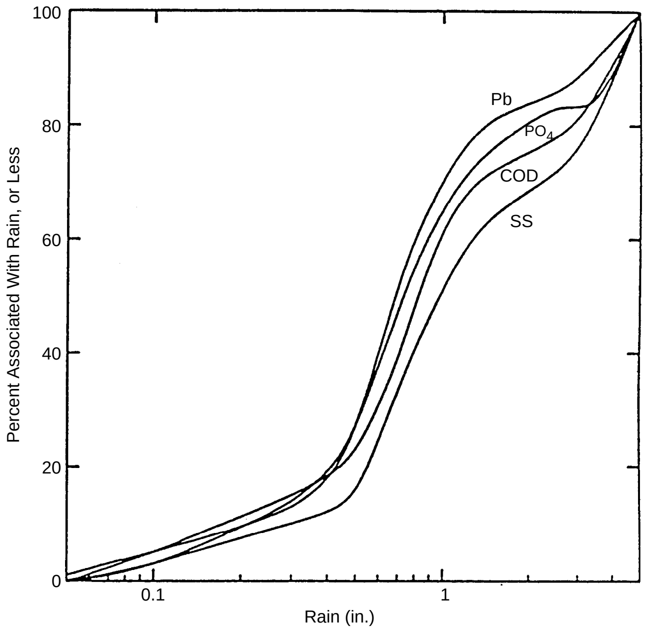


**Figure 5. Milwaukee pollutant discharge distributions (medium-density residential area).**

large storms (3 to 5 in. in depth) distort Figure 4 because, on average, the Milwaukee area only can expect one 3.5-in. storm every 5 years. If these large rains did not occur in most years, then the significance of the small rains would be even greater.

Figure 5 shows the accumulative loadings of different pollutants (suspended solids, chemical oxygen demand, phosphates, and lead) monitored during 1983 in Milwaukee at the same site as the rain and runoff data shown in Figure 4 (11). When Figure 5 is compared with Figure 4, runoff and discharge distributions appear very similar. This is a simple way of indicating that no significant trends of stormwater concentrations were observed for different size events. Substantial variations in pollutant concentrations were observed, but these were random and not related to storm size. Similar conclusions were noted when all of the NURP data were evaluated (5). Therefore, accurately knowing the runoff volume is very important when studying pollutant discharges. By better understanding the significance and runoff generation potential of these small rains, runoff problems will be better understood.

Figure 6 illustrates the concept of variable contributing areas as applied to urban watersheds. This figure indicates the relative significance of three major source areas (street surfaces, other impervious surfaces, and pervious surfaces) in an urban area. The individual flow rates associated with each of these source areas increase until their time of concentrations are met. The flow rate then remains constant for each source area until the rain event ends. When the rain stops, runoff recession curves occur, draining the individual source areas. The three component hydrographs are then added together to form the complete hydrograph for the

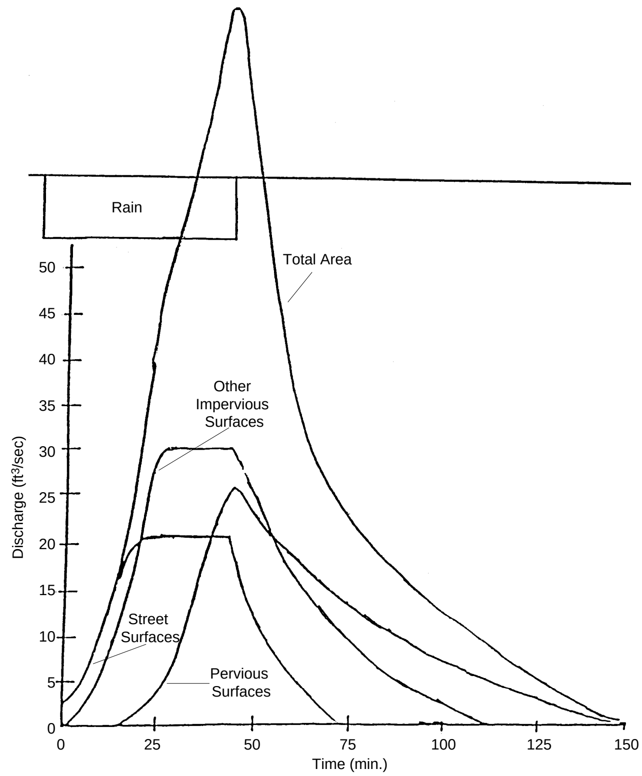


**Figure 6. Variable contributing areas in urban watersheds.**

area. Calculating the percentage of the total hydrograph associated with each individual source area enables estimates of the relative importance of each source area to be quantified. The relative pollutant discharges from each area can then be calculated from the runoff pollutant strengths associated with each area.

When the time of concentration and the rain duration are equal for an area, the maximum runoff rate for that rain intensity is reached (12). The time of concentration occurs when the complete drainage area is contributing runoff to the point of concern. If the rain duration exceeds the time of concentration, then the maximum runoff rate is maintained until the rain ends. When the rain ends, the runoff rate decreases according to a recession curve for that surface. The example shown in Figure 6 is for a rain duration greater than the times of concentrations for the street surfaces and other impervious areas, but shorter than the time of concentration for the pervious areas. Similar runoff quantities originated from each of the three source areas for this example. If the same rain intensity occurs but lasts for twice the duration (a less frequent storm), the runoff rates for the street surfaces and other impervious surfaces will be the same until the end of the rain, when their recession curves would begin. The pervious surface contribution would increase substantially, however, because its time of concentration may be exceeded by the longer rain duration. If the same rain intensity occurs but only for half of the original duration, the street surfaces time of concentration is barely met, and the other impervious surfaces would not have reached their time of concentration. In this last example, the pervious surfaces would barely begin to cause runoff. In this last case, the street surfaces are the dominant source of runoff water. By knowing the relative contributions of water and pollutants from each source area, it is possible to evaluate potential source area runoff controls for different rains.

Figure 7 shows monitored rainfall-runoff results from one of a series of tests conducted to investigate runoff losses associated with common small rains on pavement (13). This figure indicates that initial abstractions (detention storage plus evaporation losses) for this pavement totaled about 1 mm, while the total rainfall losses were about 6 mm. These maximum losses occurred after about 20 mm of rain. For a relatively small rain of about 7 mm, almost one-half of the rain falling on this pavement did not contribute to runoff. During smaller storms, the majority of the rainfall did not contribute to runoff. These rainfall losses for pavement are substantially greater than commonly considered in stormwater models. Most stormwater models use rainfall-runoff relationships that have been developed and used for many years for drainage design. Drainage design is concerned with rain depths of at least several inches. When these same procedures are used to estimate the runoff associated with common small storms (which are the most important in water quality investigations), the runoff predictions can be highly inaccurate. As an example, Figure 8 is a plot of

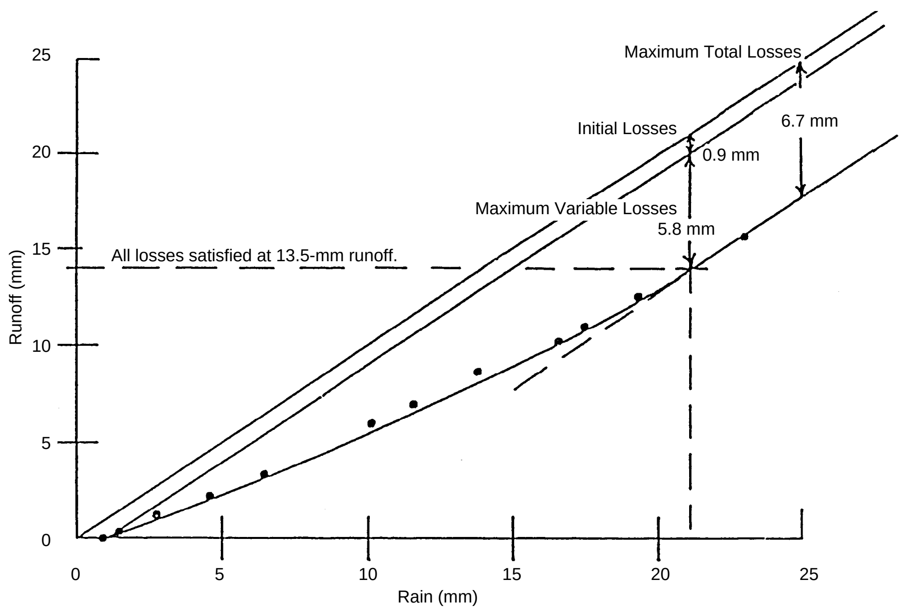


**Figure 7. Rainfall-Runoff plot (example for high-intensity rains, clean and rough streets) (13).**

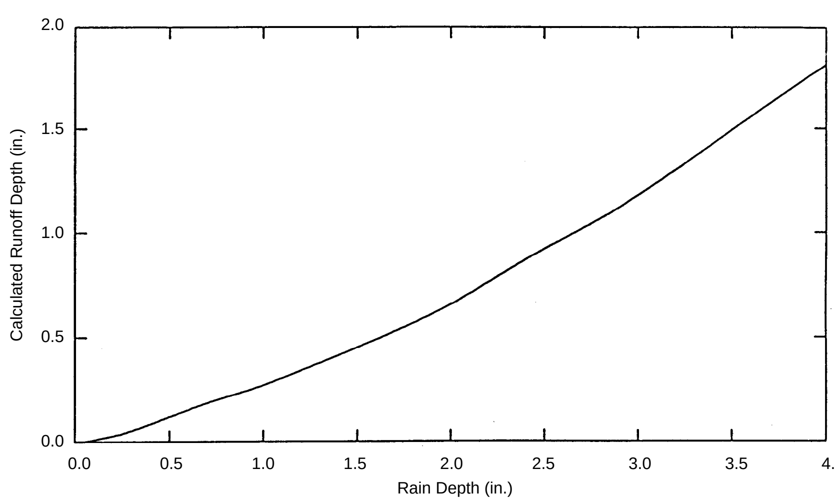


**Figure 8. Rainfall-Runoff plot (medium-density area with clayey soils).**

the observed runoff for different rain depths in Milwaukee during the 1983 NURP investigations. It was noted previously that several storms were monitored during this period that were very large. The volumetric runoff coefficient (the ratio of runoff to rain depth) observed varies for each rain depth. This ratio can be about 0.1 for storms of about 0.5 in. but may approach 0.4 for a moderate size storm of 2.5 in. or greater which is typically associated with drainage events. The NURP study (5), however, recommended the use of constant (average) volumetric runoff coefficients for the stormwater permit process. Therefore, the runoff volumes of common small storms would most likely be overpredicted.

Figure 9 shows the calculated SCS (14) CNs associated with different storms at a medium density residential site in Milwaukee. This figure shows that the CN values vary dramatically for the different rain depths that actually occurred at this site. The CN values approach the CN values that would be selected for this type of site only for rains greater than several inches in depth. The CN values are substantially greater for the smaller common storms, especially for rains less than the 1-in. minimum rain criteria given by SCS (14) for the use of this procedure. These results are similar to those obtained at many other sites. In almost all cases, the CN values for storms of less than 0.5 in. are 90 or greater. Therefore, the smaller storms contribute much more runoff than would typically be assumed if using SCS procedures. The CN method was initially developed, and is most appropriate, for use in the design of drainage systems associated with storms of much greater size than those of interest in stormwater quality investigations.

SLAMM makes runoff predictions using the small storm hydrology methods developed by Pitt (13). Figure 10

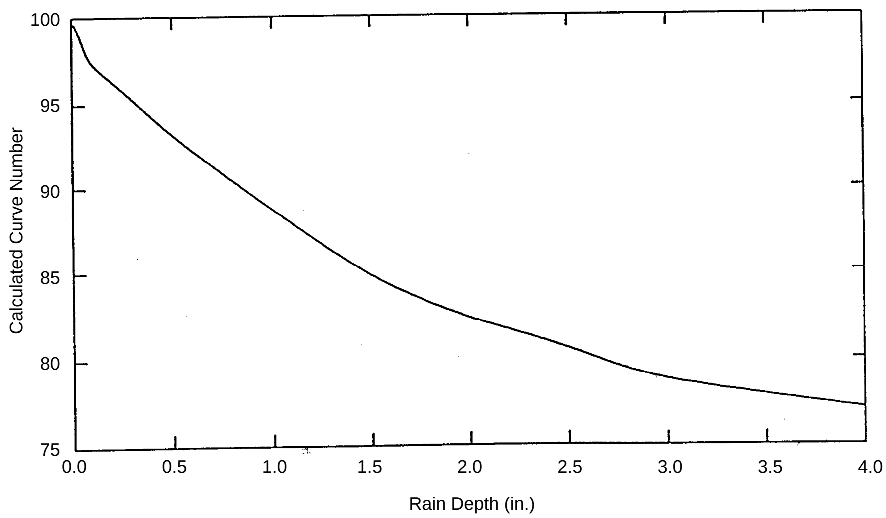


**Figure 9. Curve number changes for different rain depths (medium-density area with clayey soils).**

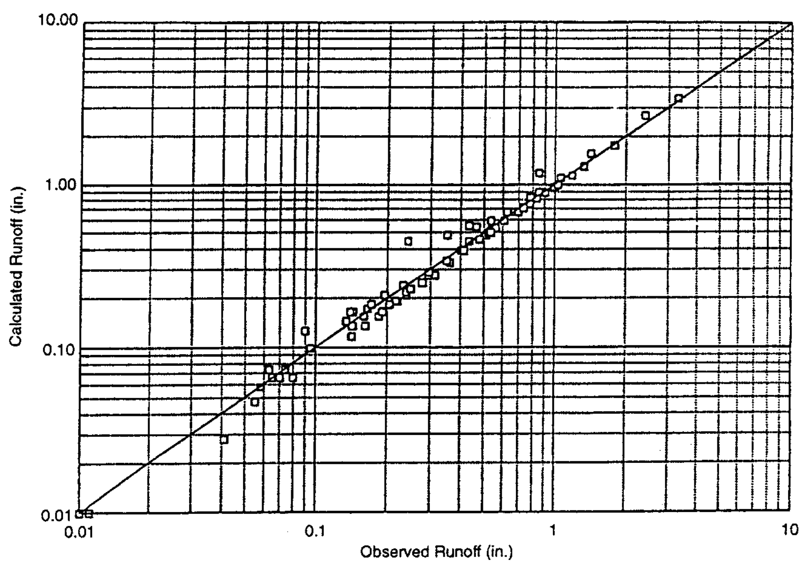


**Figure 10. Commercial shopping center runoff verification.**

shows the verification of the small storm hydrology method used in SLAMM for storms from a commercial area in Milwaukee. This figure shows that the calculated runoff for many storms over a wide range of conditions was very close to the actual observed runoff. Figure 11 shows a similar plot of the predicted versus observed runoff for a Milwaukee medium density residential area. These two sites were substantially different from each other in the amount of impervious surfaces and in the way these areas were connected to the drainage system. Similar satisfactory comparisons using these small storm hydrology models for a wide range of rain events have been made for other locations, including Portland, Oregon (15), and Toronto, Canada (8).

### *Particulate Washoff*

Another unique feature of SLAMM is its use of a washoff model to predict the losses of suspended solids from different surfaces. Figure 12 is a plot of the suspended solids concentrations for different rain depths for sheetflow runoff from paved surfaces during controlled tests in Toronto (13). This figure shows local “first-flush” effects, with a trend of decreasing suspended solids concentration with increasing rain depth. During the smallest rains, these concentrations are shown to be about several hundred milligrams per liter, and as high as 4,000 mg/L. The suspended solids concentrations during the largest events (about 1 in. in depth) decreased

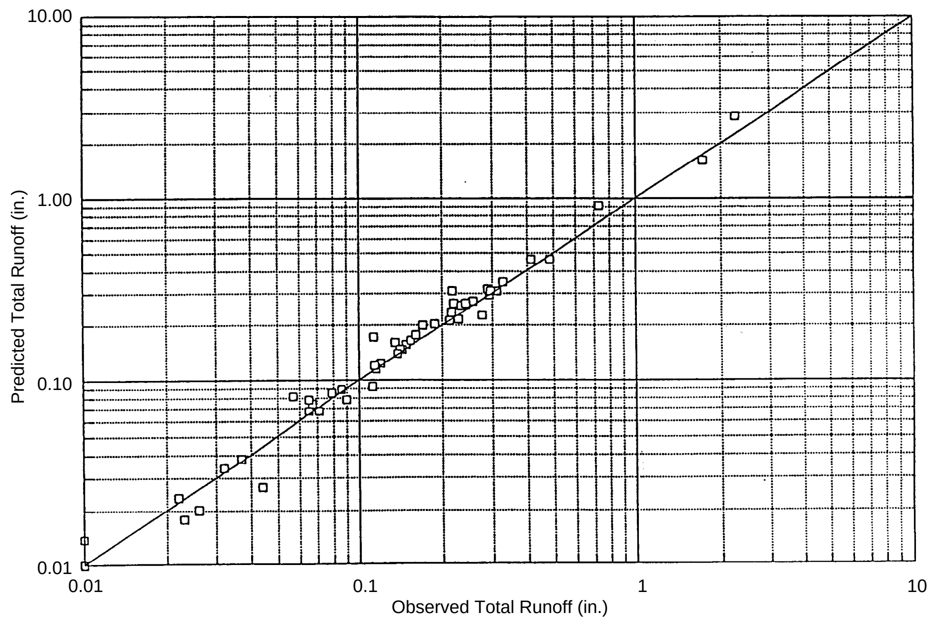


**Figure 11. Medium-density residential area runoff verification.**

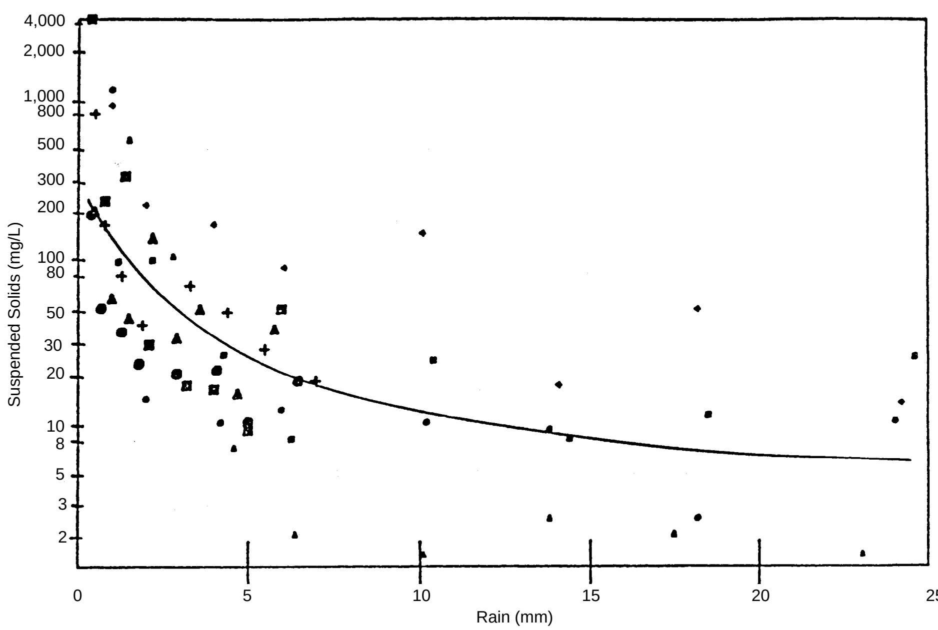


**Figure 12. Pavement “first-flush” suspended solids concentrations (13).**

dramatically to about 10 mg/L. These data were obtained during controlled small storm hydrology and particulate washoff tests using carefully controlled and constant rain intensities. A first flush of pollutants, as seen in this figure, is likely only to occur for relatively small homogeneous surfaces subjected to relatively constant rain intensities. First flushes at storm drain outfalls may not be commonly observed because of the routing of many different individual first-flush flows that are mixed. Because the highest concentrations associated with these individual flows reach the outfall at different times, these individual first flushes are mixed and lost. More significantly, later times during a rain may have much higher periods of peak rain intensities, resulting in peak washoff late in a storm. Intermittent periods of high rain intensities later in rains likely cause localized periods of high runoff pollutant concentrations that may occur long after the beginning of the rain. Therefore, first-flush situations are most likely to occur for homogeneous drainage areas (such as for large paved areas or roofs) during relatively constant rain intensities.

SLAMM calculates suspended solids washoff based on individual first-flush (exponential) plots for each surface. These plots are derived from observations during rains and during controlled tests (8). The use of individual surface washoff plots has been verified using runoff observations from large and complex drainages (13). Figures 13 through 15 show washoff plots for total solids, suspended solids (>0.45 µm), and dissolved solids (<0.45 µm) during an example controlled street surface washoff test (13). These plots indicate the accumulative gram per square meter washoff as a function of rain

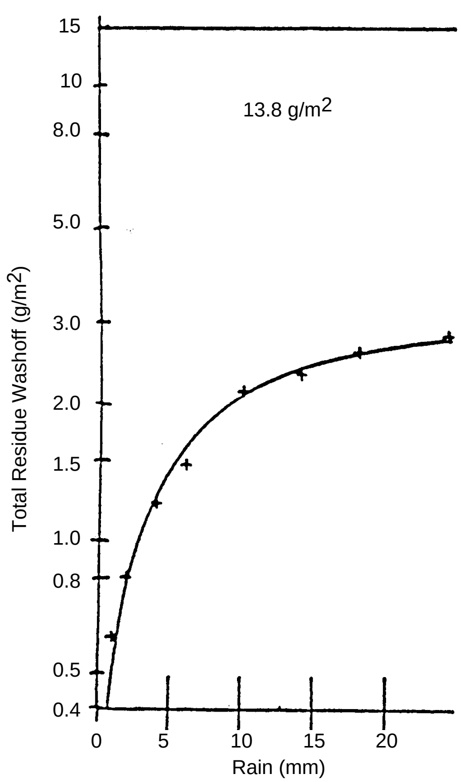


**Figure 13. Total solids washoff test results (13).**

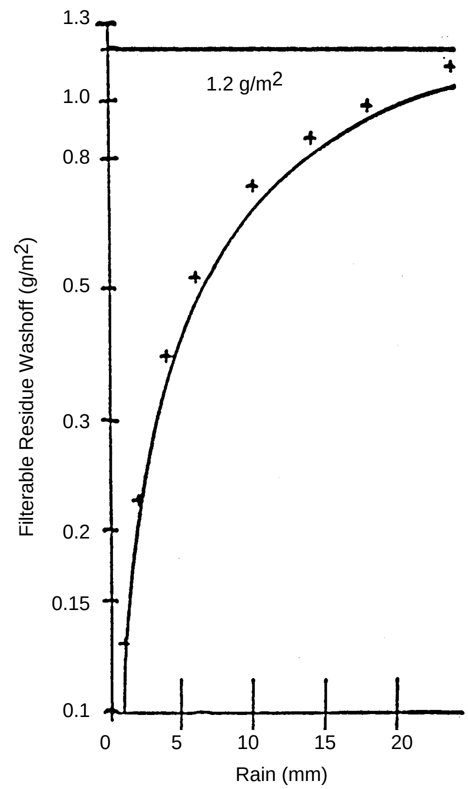


**Figure 14. Dissolved solids washoff test results (13).**

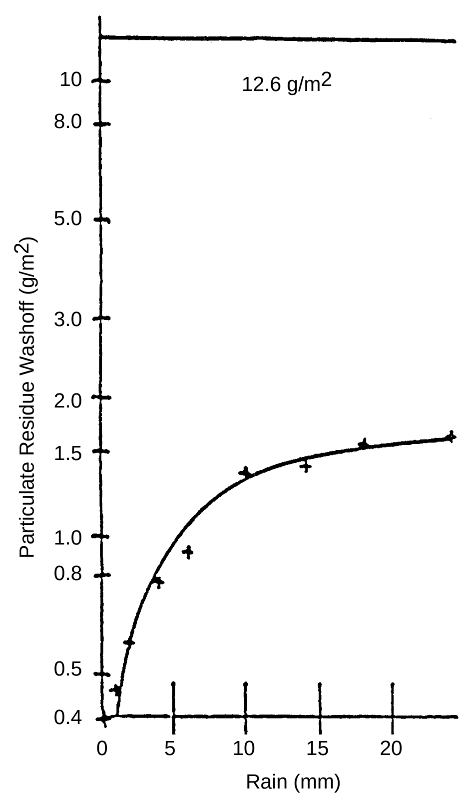


**Figure 15. Suspended solids washoff test results (13).**

depth. Also shown on these figures are the total street dirt loadings. As an example, Figure 13 shows that 13.8 g/m$^2$ of total solids were on the street surfaces before the controlled rain event. After about 15 mm of rain fell on the test sites, almost 90 percent of the particulates that would wash off (about 3 g/m$^2$) did, similar to the rain depth needed for "complete" washoff as reported by earlier studies by Sartor and Boyd (16). The total quantity of material that could possibly wash off (about 3 g/m$^2$), however, is a small fraction of the total loading that was on the street (13.8 g/m$^2$). If the relationship between total available loading and total loading of particulates is not considered (as in many stormwater models), then the predicted washoff would be greatly in error.

Figure 14 is similar to Figure 13 but shows the smallest particle sizes ("dissolved solids," < 0.45 µm) as a function of washoff. Here, the total loading of the filterable solids on the streets was only about 1 g/m$^2$, and almost all of these small particles were available for washoff during these rains. Figure 15 shows the washoff of largest particles ("suspended solids," > 0.45 µm) on the street. Here, the street loading was 12.6 g/m$^2$, with only about 1.8 g/m$^2$ available for washoff. The predicted washoff of suspended solids could be in error by 700 percent if the total loading on the street was assumed to be removable by rains. SLAMM uses test results from Pitt (13) that measured the washoff and street dirt loading availability relationships for many street surfaces, rain intensities, and street dirt loadings to more accurately predict the amount of washoff.

Another common problem with stormwater models is the use of incorrect particulate accumulation rates for different surfaces. Figure 16 shows an example of the accumulation and deposition of street surface particulates for two residential areas monitored in San Jose, California (2). The two areas were very similar in land use but the street textures were quite different. The good condition asphalt streets were quite smooth, while the oil and screens overlaid streets were very rough. Immediately after intensive street cleaning, the rough streets still had substantial particulate loadings, while the smooth streets had substantially less. The accumulation of debris on the streets also increased the street dirt loadings over time.

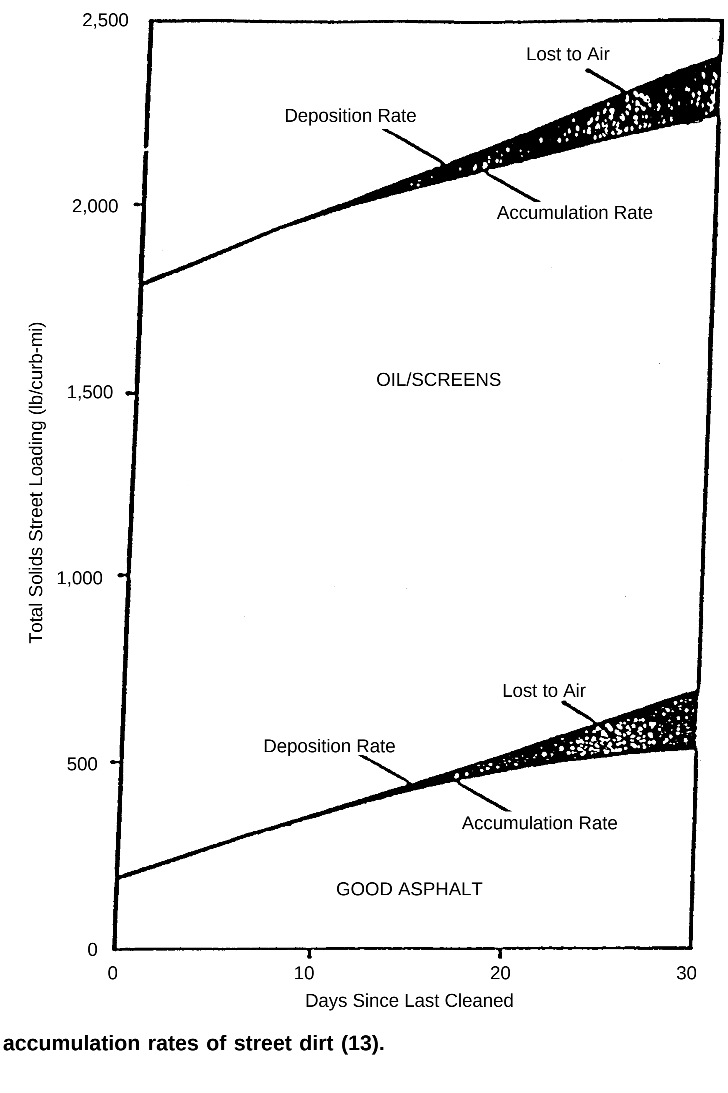


**Figure 16. Deposition and accumulation rates of street dirt (13).**

The accumulation rates were very similar for these two different streets having the same land uses. The loadings on the streets at any given time, however, were quite different because of the greatly different initial loading values (permanent storage loadings). If infrequent street dirt loading observations are made, the true shape of the accumulation rate curve may not be accurately known. As an example, the early Sartor and Boyd (16) test results that have been used in many stormwater models assumed that the initial loading values after rains were close to zero, instead of the actual substantial initial loadings. The accumulation rates were calculated by using the slope between each individual loading value and the origin (zero time and zero loading), rather than between loadings from adjacent sampling times, which can easily result in accumulation rates many times greater than actually occurred.

The street dirt deposition rates were found to be only a function of the land uses, but the street dirt loadings were a function of the land use and street texture. The accumulation rates slowly decreased as a function of time and eventually became zero, with the loading remaining constant after a period of about 1 month of either no street cleaning or no rains. Figure 16 shows that the deposition and accumulation rates on the streets were about the same until about 1 or 2 weeks after a rain. If the streets were not cleaned for longer periods, then the accumulation rate decreased because of fugitive dust losses of street dirt to surrounding areas by winds or vehicle turbulence. In most areas of the United States (having rains at least every week or two), the actual accumulation of material on street surfaces is likely constant, with little fugitive dust losses (2).

SLAMM includes a large number of street dirt accumulation and deposition rate relationships that have been obtained for many monitoring sites throughout the United States and Canada. The accumulation rates are a function of the land uses, while the initial loadings on the streets are a function of street texture. The decreasing accumulation rate is also a function of the time after a street cleaning or large rain event.

## Monte Carlo Simulation of Pollutants Strengths Associated With Runoff From Various Urban Source Areas

Initial versions of SLAMM only used average concentration factors for different land-use areas and source areas. This was satisfactory for predicting the event mean concentrations (EMC, as used by NURP [5]) for an extended period and for calculating the unit area loadings for different land uses. Figure 17 is a plot of the event mean concentrations at a Toronto test site (8). The observed concentrations are compared with the SLAMM predicted concentrations for a long-term simulation. All of the predicted EMC values are close to the observed EMC values. To predict the probability distributions of the concentrations, however, it was necessary to include probability information for the concentrations found in the different source areas. Statistical analyses of concentration data (attempting to relate concentration trends to rain depths and season, for example) from these different source areas have not been able to explain all of the observed variations in concentration. The statistical analyses also indicate that pollutant concentration values from individual source areas are distributed log normally. Therefore, log-normally distributed random concentration values are used in SLAMM

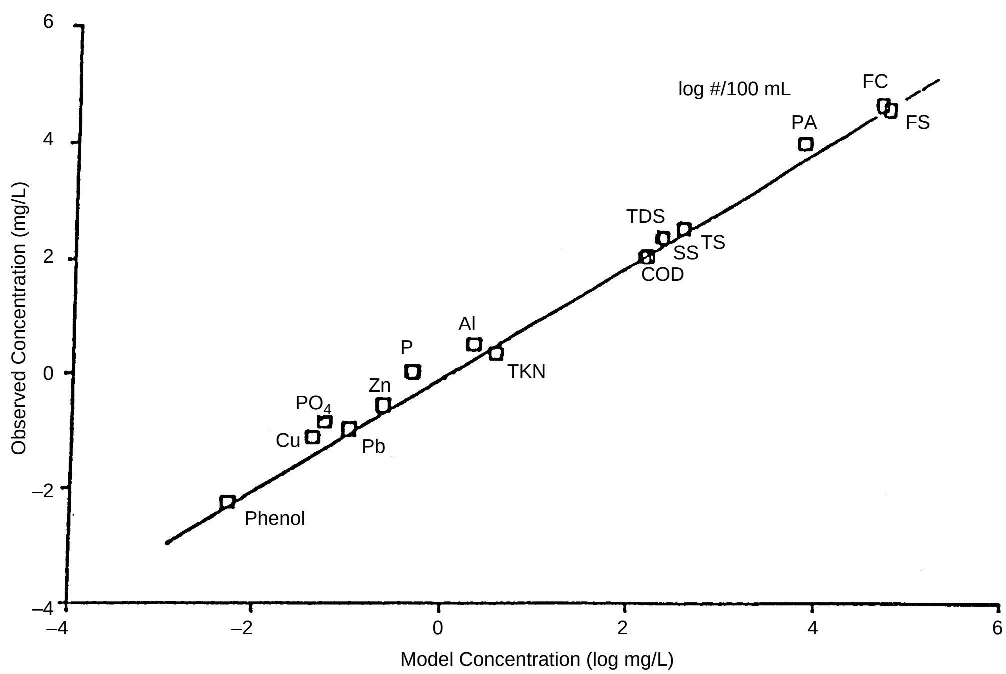


**Figure 17. Observed and modeled pollutant concentrations (Toronto industrial site) (8).**

for these different areas. The results are predictions for concentration distributions at the outfall. This can provide estimates of criteria violations for different stormwater pollutants at an outfall for long, continuous simulations.

## An Example Analysis Using SLAMM To Identify the Sources of Pollutants and To Evaluate Different Control Programs

Table 2 is a field sheet that has been developed to assist users of SLAMM to describe test watershed areas. This sheet is used to evaluate stormwater control retrofit practices in existing developed areas, and to examine how different new development standards effect runoff conditions. Much of the information on the sheet is not actually required to operate SLAMM but is very important when considering additional control programs, such as public education and good housekeeping practices, that are not quantified by SLAMM. The most important information shown on this sheet is the land use, the type of the gutter or drainage system, and the method of drainage from roofs and large paved areas to the drainage system. The efficiency of drainage in an area, specifically if roof runoff or parking runoff drains across grass surfaces, can be very important when determining the amount of water and pollutants that enter the outfall system. Similarly, the presence of grass swales in an area may substantially reduce the amount of pollutants and water discharged. This information is therefore required to use SLAMM.

The areas of the different surfaces in each land use are also very important for SLAMM. Figure 18 is an example showing the areas of different surfaces for a medium density residential area in Milwaukee. As shown in this

**Table 2. Study Area Descriptions**

| | | | | | |
|---|---|---|---|---|---|
| **Location:** | | | **Site number:** | | |
| **Date:** | | | **Time:** | | |
| **Photo numbers:** | | | **Roll number:** | | |
| Land-use and industrial activity: | | | | | |
| Residential: | Low | Medium | High-density single family | | |
| | Multiple family | | | | |
| | Trailer parks | | | | |
| | High-rise apartments | | | | |
| Income level: | Low | Medium | High | | |
| Age of development: | <1930 | ’30-’50 | ’51-’70 | ’71-’80 | New |
| Institutional: | School | Hospital | Other (type): | | |
| Commercial: | Strip | Shopping center | Downtown | Hotel | Offices |
| Industrial: | Light | Medium | Heavy (manufacturing) | Describe: | |
| Open space: | Undeveloped | Park | Golf | Cemetery | |
| Other: | Freeway | Utility ROW | Railroad ROW | Other: | |
| Maintenance of building: | Excellent | Moderate | Poor | | |
| Heights of buildings: | 1 | 2 | 3 | 4+ stories | |
| Roof drains: | Underground | Gutter | Impervious | Pervious | |
| Roof types: | Flat | Comp. shingle | Wood shingle | Other: | |
| Sediment source nearby? | No | Yes (describe): | | | |
| Treated wood near street? | No | Telephone poles | Fence | Other: | |
| Landscaping near road: | | | | | |
| Quantity: | None | Some | Much | | |
| Type: | Deciduous | Evergreen | Lawn | | |
| Maintenance: | Excessive | Adequate | Poor | | |
| Leaves on street: | None | Some | Much | | |
| Topography: | | | | | |
| Street slope: | Flat (<2%) | Medium (2-5%) | Steep (>5%) | | |
| Land slope: | Flat (<2%) | Medium (2-5%) | Steep (>5%) | | |
| Traffic speed: | <25 mph | 25–40 mph | >40 mph | | |

**Table 2. Study Area Descriptions (continued)**

| | | | | |
|---|---|---|---|---|
| Traffic density: | Light | Moderate | Heavy | |
| Parking density: | None | Light | Moderate | Heavy |
| Width of street: | | | | |
| Number of parking lanes: | | | | |
| Number of driving lanes: | | | | |
| Condition of street: | Good | Fair | Poor | |
| Texture of street: | Smooth | Intermediate | Rough | |
| Pavement material: | Asphalt | Concrete | Unpaved | |
| Driveways: | Paved | Unpaved | | |
| Condition: | Good | Fair | Poor | |
| Texture: | Smooth | Intermediate | Rough | |
| Gutter material: | Grass swale | Lined ditch | Concrete | Asphalt |
| Condition: | Good | Fair | Poor | |
| Street/Gutter interface: | Smooth | Fair | Uneven | |
| Litter loadings near street: | Clean | Fair | Dirty | |
| Parking/Storage areas (describe): | | | | |
| Condition of pavement: | Good | Fair | Poor | |
| Texture of pavement: | Smooth | Intermediate | Rough | Unpaved |
| Other paved areas, such as alleys and playgrounds (describe): | | | | |
| Condition of pavement: | Good | Fair | Poor | |
| Texture of pavement: | Smooth | Intermediate | Rough | Unpaved |
| Notes: | | | | |

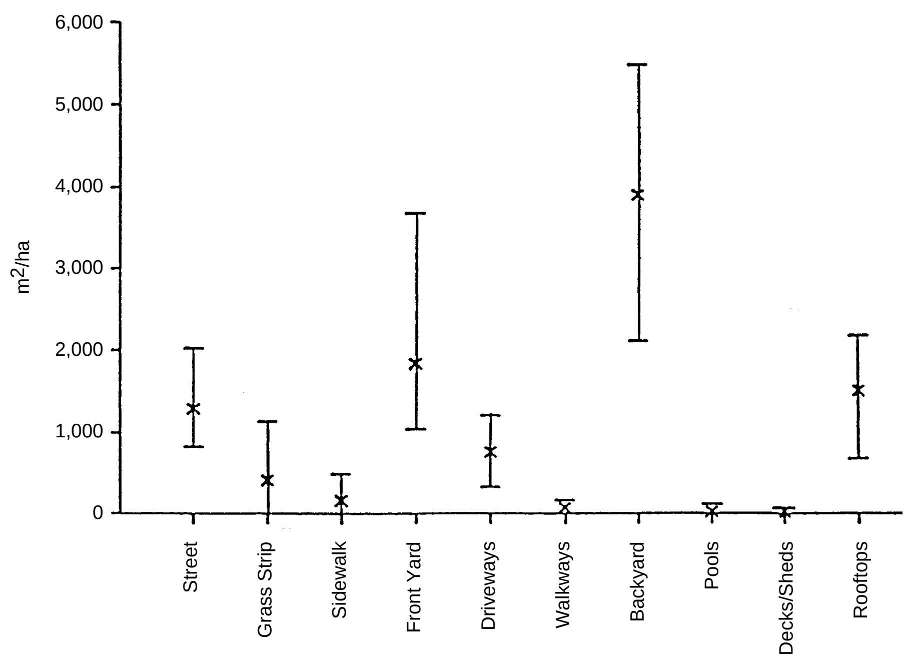


**Figure 18. Source areas: Milwaukee medium-density residential areas (without alleys).**

example, streets make up between 10 and 20 percent of the total area, while landscaped areas can make up about half of the drainage area. The variation of these different surfaces can be very large within a designated area. The analysis of many candidate areas may therefore be necessary to understand how effective or consistent the model results may be for a general land-use classification.

Control practices evaluated by SLAMM include infiltration trenches, seepage pits, disconnections of directly connected roofs and paved areas, percolation ponds, street cleaning, porous pavements, catchbasin cleaning, grass swales, and wet detention ponds. These devices can be used singly or in combination, at source areas or at outfalls, or, in the case of grass swales and catchbasins, within the drainage system. In addition, SLAMM provides a great deal of flexibility in describing the sizes and other design aspects for these different practices.

One of the first problems in evaluating an urban area for stormwater controls is the need to understand where the pollutants of concern are originating under different rain conditions. Figures 19 through 22 are examples for a typical medium density residential area showing the percentage of different pollutants originating from different major sources, as a function of rain depth. As an example, Figure 19 shows the areas where water is originating. For storms of up to about 0.1 in. in depth, street surfaces contribute about one-half to the total runoff to the outfall. This contribution decreased to about 20 percent for storms greater than about 0.25 in. in depth. This decrease in the significance of streets as a source of water is associated with an increase in water contributions from landscaped areas (which make up more than 75 percent of the area and have clayey soils). Similarly, the significance of runoff from driveways and roofs also starts off relatively high and then decreases with increasing storm depth. Figures 20 and 21 are similar plots for suspended solids and lead. These show that streets contribute almost all of these pollutants for the smallest storms up to about 0.1 in. The contributions from landscaped areas then become dominant. Figure 22 shows that the contributions of phosphates are more evenly distributed between streets, driveways, and rooftops for the small storms, but the contributions from landscaped areas completely dominate for storms greater than about 0.25 in. in depth.

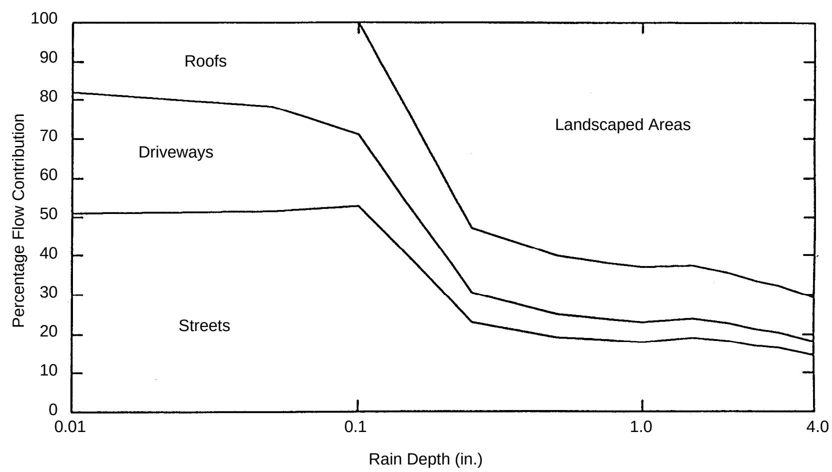


**Figure 19. Flow sources for example medium-density residential area having clayey soils.**

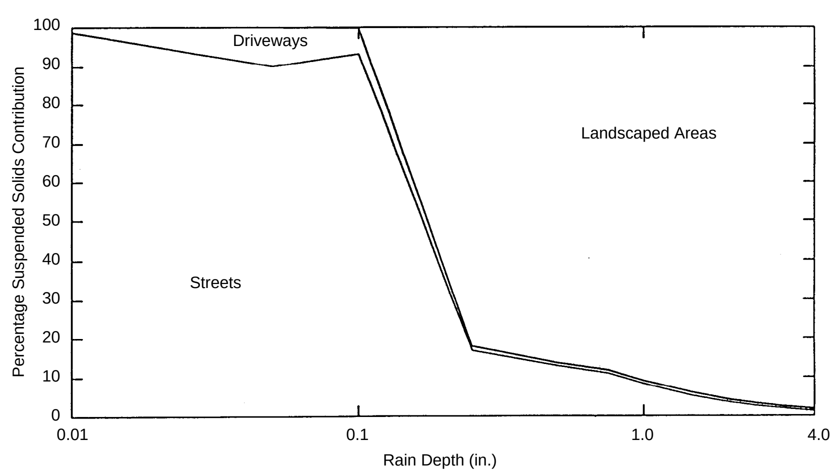


**Figure 20. Suspended solids sources for example medium-density residential area.**

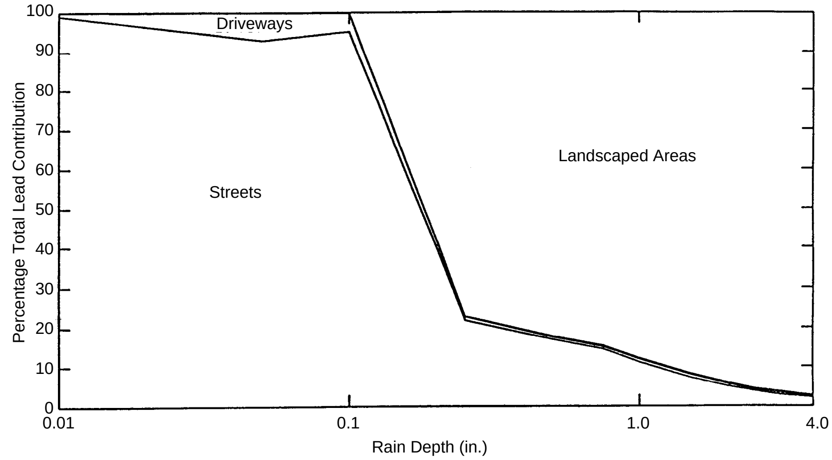


**Figure 21. Total lead sources for example medium-density residential area.**

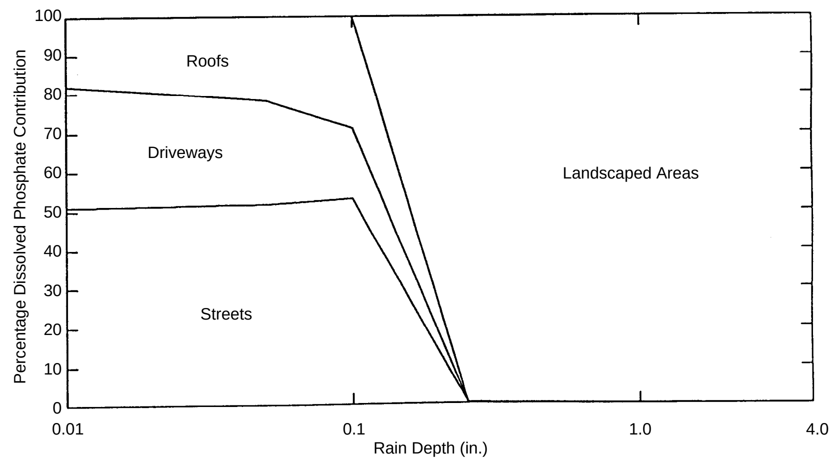


**Figure 22. Dissolved phosphate sources for example medium-density residential area.**

Obviously, the specific contributions from different areas and for different pollutants vary dramatically, depending on the characteristics of development for the area and the source controls used. Again, a major use of SLAMM is to better understand the role of different sources of pollutants. As an example, to control suspended solids, street cleaning (or any other method to reduce the washoff of particulates from streets) may be very effective for the smallest storms but would have very little benefit for storms greater than about 0.25 in. in depth. Erosion control from landscaped surfaces, however, may be effective over a wider range of storms.

The following list shows the different control programs that were investigated in this hypothetical medium density residential area having clayey soils:

- Base level (as built in 1961 to 1980, with no additional controls).
- Catchbasin cleaning.
- Street cleaning.
- Grass swales.
- Roof disconnections.
- Wet detention pond.
- Catchbasin and street cleaning combined.
- Roof disconnections and grass swales combined.
- All of the controls combined.

This residential area, which was based on actual Birmingham, Alabama, field observations for homes built between 1961 to 1980, has no controls. The use of catchbasin cleaning and street cleaning in the area was evaluated. Grass swale use was also evaluated, but swales are an unlikely retrofit option and would only be appropriate for newly developing areas. It is possible, however, to disconnect some of the roof drainages and divert the roof runoff away from the drainage system and onto grass surfaces for infiltration in existing developments. In addition, wet detention ponds can be retrofitted in different areas and at outfalls. Besides those controls examined individually, catchbasin and street cleaning controls combined were also evaluated, in addition to the combination of disconnecting some of the rooftops and the use of grass swales. Finally, the prospect of using all of the controls together was examined.

The following list shows a general description of this hypothetical area:

- All curb and gutter drainage (in fair condition).
- 70 percent of roofs draining to landscaped areas.
- 50 percent of driveways draining to lawns.
- 90 percent of streets of intermediate texture (remaining are rough).
- No street cleaning.
- No catchbasins.

About one-half of the driveways currently drain to landscaped areas, while the other half drain directly to the pavement or the drainage system. Almost all of the streets are of intermediate texture, and about 10 percent are rough textured. There currently is no street cleaning or catchbasin cleaning.

The level of catchbasin use that was investigated for this site included 950 $ft^3$ of total sump volume per 100 acres (typical for this land use), with a cost of about $50 per catchbasin cleaning. Typically, catch basins in this area could be cleaned about twice a year for a total annual cost of about $85 per acre of the watershed.

Street cleaning could also be used, with a monthly cleaning effort of about $30 per year per watershed acre. Light parking and no parking restrictions during cleaning are assumed, and the cleaning cost is estimated to be $80 per curb mile.

Grass swale drainage was also investigated. Assuming that swales could be used throughout the area, there could be 350 ft of swales per acre (typical for this land use), with swales 3.5 ft wide. Because of the clayey soil conditions, an average infiltration rate of about 0.5 in./hr was used in this analysis based on many different double-ring infiltrometer tests of typical soil conditions. Swales cost much less than conventional curb and gutter systems but require increased maintenance. Again, the use of grass swales is appropriate for new development but not for retrofitting in this area.

Roof disconnections could also be used as a control measure by directing all roof drains to landscaped areas. The objective would be to direct all the roof drains to landscaped areas. Because 70 percent of the roofs already drain to the landscaped areas, only 30 percent could be further disconnected, at a cost of about $125 per household. The estimated total annual cost would be about $10 per watershed acre.

An outfall wet detention pond suitable for 100 acres of this medium density residential area would have a wet pond surface of 0.5 percent of drainage area for approximately 90 percent suspended solids control. It would need 3 ft of dead storage and live storage equal to runoff from 1.25-in. rain. A 90-degree V notch weir and a 5-ft wide emergency spillway could be used. No seepage or evaporation was assumed. The total annual cost was estimated to be about $130 per watershed acre.

Table 3 summarizes the SLAMM results for runoff volume, suspended solids, filterable phosphate, and total lead for 100 acres of this medium density residential area. The only control practices evaluated that would reduce runoff volume are the grass swales and roof disconnections. All of the other control practices evaluated do not infiltrate stormwater. Table 3 also shows the total annual average volumetric runoff coefficient (Rv) for these different options. The base level of control has an annual flow-weighted Rv of about 0.3, while the use of swales would reduce the Rv to about 0.1. Only a small reduction of Rv (less than 10 percent) would be associated with complete roof disconnections compared with the existing situation because of the large amount of roof disconnections that already occur. The suspended solids analyses shows that catchbasin cleaning alone could result in about 14 percent suspended solids reductions. Street cleaning would have very little benefit, while the use of grass swales would reduce the suspended solids discharges by about 60 percent. Grass swales would have minimal effect on the reduction of suspended solids concentrations at the outfall. (They are primarily an infiltration device, having very little filtering benefits.) Wet detention ponds would remove about 90 percent of the mass and concentrations of suspended solids. Similar observations can be made for filterable phosphates and lead.

Figures 23 through 26 show the maximum percentage reductions in runoff volume and pollutants, along with associated unit removal costs. As an example, Figure 23 shows that roof disconnections would have a very small potential maximum benefit for runoff volume reduction, at a very high unit cost compared with other practices. The use of grass swales could have about a 60-percent reduction at minimal cost. The use of roof disconnection plus swales would slightly increase the maximum benefit to about 65 percent, at a small unit cost. Obviously, the use of roof disconnections alone, or all controlled practices combined, is very inefficient for this example. For suspended solids control, catchbasin cleaning and street cleaning would have minimal benefit at high cost, while the use of grass swales would produce a substantial benefit at very small cost. If additional control is necessary, however, the use of wet detention ponds may be necessary at a higher cost. If close to a 95-percent reduction of suspended solids was required, then all of the controls investigated could be used together, but at substantial cost.

**Table 3. SLAMM Predicted Runoff and Pollutant Discharge Conditions for Example**[a]

| Birmingham 1976 rains (112 rains, 55 in. total, 0.01-3.384 in. each) | Runoff Volume | | | Suspended Solids | | Filterable Phosphate | | Total Lead | |
|---|---|---|---|---|---|---|---|---|---|
| | Annual $ft^3$/acre | Flow-wtg Rv | CN Range | Flow-wtg mg/L | Annual lb/acre | Flow-wtg µg/L | Annual lb/acre | Flow-wtg µg/L | Annual lb/acre |
| Base (no controls) | 59,800 | 0.3 | 77-100 | 385 | 1,430 | 157 | 0.58 | 543 | 2.0 |
| Catchbasin cleaning: | 59,800 | 0.3 | 77-100 | 331 | 1,230 | 157 | 0.58 | 468 | 1.7 |
| Reduction (lb or $ft^3$) | 0 | | | | 200 | | 0 | | 0.29 |
| Reduction (%) | 0 | | | 14 | 14 | 0 | 0 | 14 | 14 |
| Cost ($/lb or $/$ft^3$) | NA | | | | 0.43 | | NA | | 293 |
| ($85/acre/yr) | | | | | | | | | |
| Street cleaning: | 59,800 | 0.3 | 77-100 | 385 | 1,430 | 157 | 0.58 | 543 | 2.0 |
| Reduction (lb or $ft^3$) | 0 | | | | 0 | | 0 | | 0.01 |
| Reduction (%) | 0 | | | 0 | 0 | 0 | 0 | 0 | 0.49 |
| Cost ($/lb or $/$ft^3$) | NA | | | | NA | | NA | | 3,000 |
| ($30/acre/yr) | | | | | | | | | |
| Grass swales: | 23,300 | 0.12 | 63-100 | 380 | 554 | 151 | 0.22 | 513 | 0.75 |
| Reduction (lb or $ft^3$) | 36,500 | | | | 876 | | 0.36 | | 1.28 |
| Reduction (%) | 61 | | | 1 | 61 | 4 | 62 | 6 | 63 |
| Cost ($/lb or $/$ft^3$) | Minimal | | | | Minimal | | Minimal | | Minimal |
| ($minimal/acre/yr) | | | | | | | | | |
| Roof disconnections: | 56,000 | 0.28 | 76-100 | 410 | 1,430 | 156 | 0.55 | 443 | 1.6 |
| Reduction (lb or $ft^3$) | 3,800 | | | | 0 | | 0.03 | | 0.48 |
| Reduction (%) | 6 | | | -6 | 0 | 1 | 5 | 18 | 24 |
| Cost ($/lb or $/$ft^3$) | 0 | | | | NA | | 333 | | 21 |
| ($10/acre/yr) | | | | | | | | | |
| Wet detention pond: | 59,800 | 0.3 | 77-100 | 49 | 185 | 157 | 0.58 | 69 | 0.26 |
| Reduction (lb or $ft^3$) | 0 | | | | 1,250 | | 0 | | 1.8 |
| Reduction (%) | 0 | | | 87 | 87 | 0 | 0 | 87 | 87 |
| Cost ($/lb or $/$ft^3$) | NA | | | | 0.10 | | NA | | 73 |
| ($130/acre/yr) | | | | | | | | | |
| CB and street cleaning: | 59,800 | 0.3 | 77-100 | 331 | 1,230 | 157 | 0.58 | 468 | 1.7 |
| Reduction (lb or $ft^3$) | 0 | | | | 200 | | 0 | | 0.29 |
| Reduction (%) | 0 | | | 14 | 14 | 0 | 0 | 14 | 14 |
| Cost ($/lb or $/$ft^3$) | NA | | | | 0.58 | | NA | | 397 |
| ($115/acre/yr) | | | | | | | | | |
| Roof dis. and swales: | 20,900 | 0.1 | 63-100 | 403 | 526 | 139 | 0.18 | 352 | 0.46 |
| Reduction (lb or $ft^3$) | 38,900 | | | | 904 | | 0.40 | | 1.6 |
| Reduction (%) | 65 | | | -5 | 63 | 11 | 69 | 35 | 77 |
| Cost ($/lb or $/$ft^3$) | 0.00026 | | | | 0.01 | | 25 | | 6.4 |
| ($10/acre/yr) | | | | | | | | | |
| All above controls: | 20,900 | 0.1 | 63-100 | 42 | 55 | 139 | 0.18 | 36 | 0.05 |
| Reduction (lb or $ft^3$) | 38,900 | | | | 1,375 | | 0.40 | | 1.98 |
| Reduction (%) | 65 | | | 89 | 96 | 11 | 69 | 93 | 97 |
| Cost ($/lb or $/$ft^3$) | 0.0066 | | | | 0.19 | | 638 | | 129 |
| ($255/acre/yr) | | | | | | | | | |

[a]Medium-density residential area, developed in 1961-1980, with clayey soils (curbs and gutters); new development controls (not retrofit).

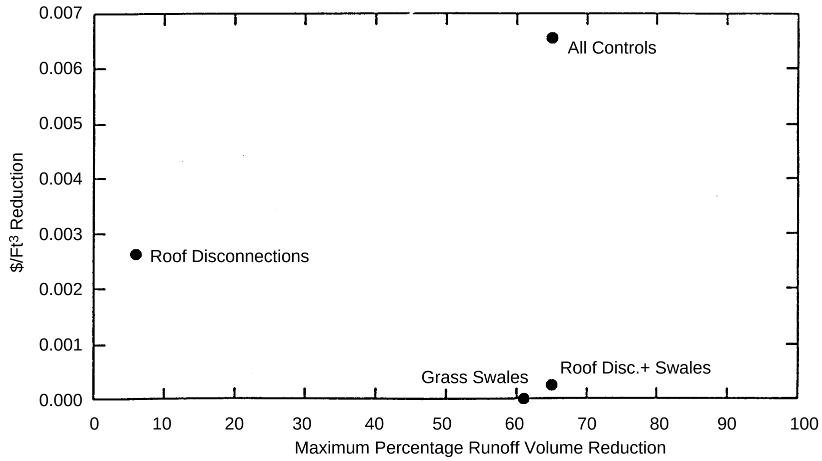


**Figure 23. Cost-effectiveness data for runoff volume reduction benefits.**

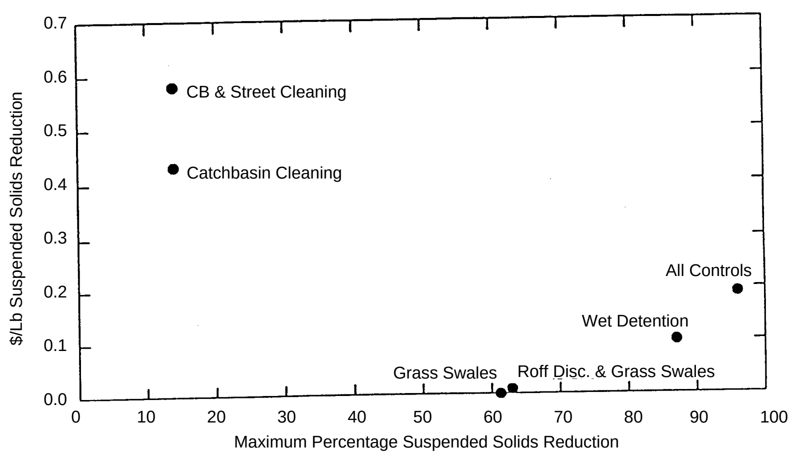


**Figure 24. Cost-effectiveness data for suspended solids reduction benefits.**

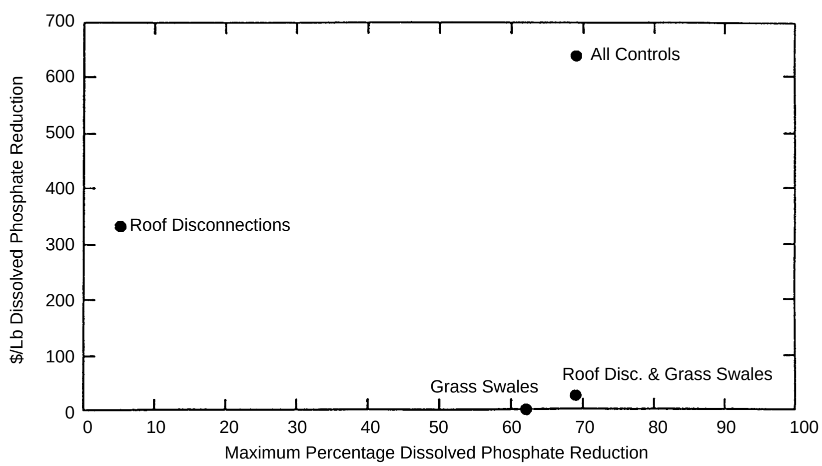


**Figure 25. Cost-effectiveness data for dissolved phosphate reduction benefits.**

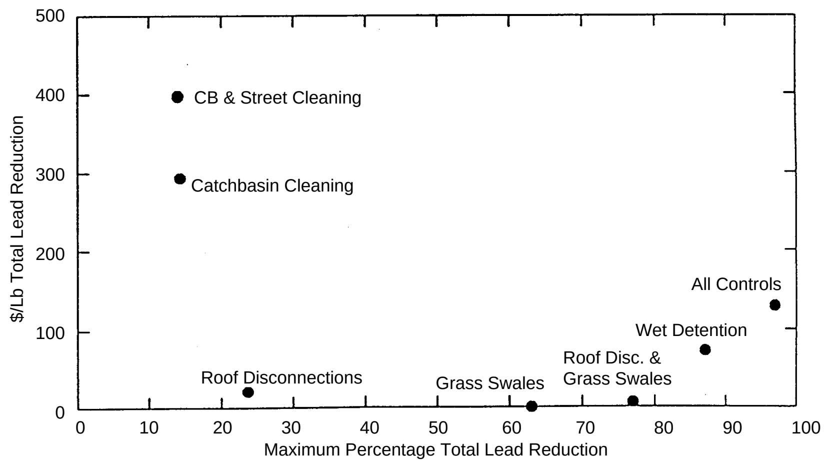


**Figure 26. Cost-effectiveness data for total lead reduction benefits.**

## Conclusions

This paper has shown how SLAMM can be used to estimate the relative contributions of different pollutants from different areas within a complex watershed. SLAMM can also be used to examine the cost effectiveness of different individual control programs, or combinations of control programs, that could be located at source areas or at the outfalls.

SLAMM is unique compared with most stormwater models. Specifically, the use of small storm hydrology to predict the contributions of runoff from different source areas and the use of particulate washoff algorithms have greatly enhanced the accuracy of SLAMM. In addition, SLAMM requires a minimum amount of information to describe the area under consideration and engineering design parameters for different control practices. SLAMM is a very useful tool in guiding planners and watershed managers in devising control strategies. It has also been used to quantify and justify the benefits associated with stormwater controls for newly developing areas.

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# Combining GIS and Modeling Tools in the Development of a Stormwater Management Program

**Chris Rodstrom, Mohammed Lahlou, and Alan Cavacas**
**Tetra Tech, Inc., Fairfax, Virginia**

**Mow-Soung Cheng**
**Department of Environmental Resources, Division of Environmental Management, Watershed Protection Branch, Prince George's County, Landover, Maryland**

## Abstract

A geographic information system (GIS) based Watershed Simulation Model (GWSM) was developed for stormwater pollution control in Prince George's County, Maryland, using the Stormwater Management Model (SWMM 4.2), ARC/INFO (6.1), and data postprocessors. The GWSM was designed to perform planning level assessments of water quality concentrations and loadings for 12 water quality parameters in 41 primary watersheds within the county. The model combines continuous watershed modeling and the spatial analysis capabilities of a GIS in a single, integrated system operating on a Sun Sparc 2 workstation. The user selects a watershed to determine daily, monthly, seasonal, or annual stormwater pollutant loadings using the SWMM output. Additional routines analyze stormwater control structures and user-defined subbasins. GWSM output is saved for watershed comparisons using both graphical and tabular formats.

GWSM allows county water resources planners to perform analyses in the following areas:

- *Prioritize problem watersheds:* Identify where impacts are most severe based on pollutant-specific data. Both temporal and spatial problems and trends are identified.
- *Integration with water quality databases:* Data from national databases, including STORET, WATSTORE, and Reachfile III streams, are used in characterizing the water resources of the study area.
- *Alternative land use assessment:* Water quality impacts and trends, based on land use changes or future master planning scenarios, can be evaluated.
- *Screening solutions/microscale analysis:* Management assessment tools provide planning level screening of controls designed to cost-effectively manage the pollutants of concern. This allows determination of which flows and loads need to be controlled. Smaller, 100- to 400-acre drainage basins can also be evaluated with alternative land uses and management practices.

## Introduction

The National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit regulations resulting from the Clean Water Act Reauthorization of 1987 require large counties and municipalities to develop comprehensive stormwater management programs. For complex urban fringe areas such as Prince George's County, Maryland, prioritizing stormwater problems and developing cost-effective management techniques is a primary objective if program resources are to be efficiently allocated. The geographic information system (GIS) based Watershed Simulation Model (GWSM) was designed to support the development and implementation of the county's stormwater management program. GWSM enables planning assessment at the watershed level through estimation of pollutant loads and flows for current land use conditions and future buildout scenarios, with or without structural controls. At the small basin level, alternative stormwater control scenarios can be evaluated for user-defined areas.

## Existing Watershed Models

A variety of models are available for simulating water quantity and quality on a watershed scale (1). These range from relatively simple empirical models that predict annual or storm loads to deterministic models that yield flow and pollutant loads for a variety of flow conditions.

Simple models, such as the U.S. Environmental Protection Agency (EPA) Screening Procedures (2) model and the Simple Method (3), commonly aggregate the physical parameters for an entire watershed and calculate loads on an annual or seasonal time step. Although this reduces the amount of input data and time required to apply the model, it does not allow for an examination of the variations between storm events or water quality problems occurring over a wide range of hydrologic conditions.

Complex models, such as SWMM (4) and the Hydrologic Simulation Program-Fortran (HSPF) (5), simulate hydrologic processes that generate runoff and pollutant loads in a continuous manner rather than relying on simplified rates of change (1). This class of model can use time series climatic data for continuous simulation over several years, enabling analysis of not only annual loads and flows but also of single events or a series of storms.

## Previous Studies

GIS is increasingly used for watershed assessment in support of various water resources programs (6). A review of available literature shows that the use of GIS in conjunction with hydrologic models comprises a major part of the current activities. The use of GIS for hydrologic modeling can be divided into two general approaches: 1) performing watershed modeling analyses directly within a GIS package using empirical or lumped models and 2) processing input data for use with a separate or partially linked watershed model.

Empirical modeling within a GIS environment includes an approach using the modified Universal Soil Loss Equation (USLE) for evaluating silvicultural activities and control programs in Montana (7). Tim et al. (8) coupled empirical simulation modeling with a GIS to identify critical areas of nonpoint source pollution in Virginia. On the other hand, linked GIS and hydrologic modeling approaches include a study by Ross and Tara (9) using a GIS to perform spatial data referencing and data processing while traditional hydrologic codes performed the calculations for time-dependent surface- and ground-water simulations. Terstriep and Lee (10) developed AUTO_QI, a GIS-based interface for watershed delineation and input data formatting to the Q-ILLUDAS model.

## Modeling Approach: The Prince George's County GIS-Based Watershed Simulation Model

The GWSM developed for the Prince George's County stormwater program combines results from a watershed model with GIS analytic routines. Figure 1 illustrates this modular modeling approach. The GWSM uses a continuous simulation model to generate single land-use water quality and quantity time series data. ARC/INFO, combining GIS coverages from various databases, is used to select a watershed and determine its physical characteristics, including drainage area and land-use distribution. The single land-use time series, along with the land-use and drainage area files, are processed by a series of Fortran routines to determine watershed loads and summary statistics (Figure 1). Results can be interactively displayed for watershed comparisons and management assessment. As with AUTO_QI (10), the GWSM modeling approach uses the GIS to furnish data for use with a continuous simulation model. Unlike other approaches, however, GWSM uses preprocessed output from a watershed model to calculate storm flows and pollutant loads for the study watershed.

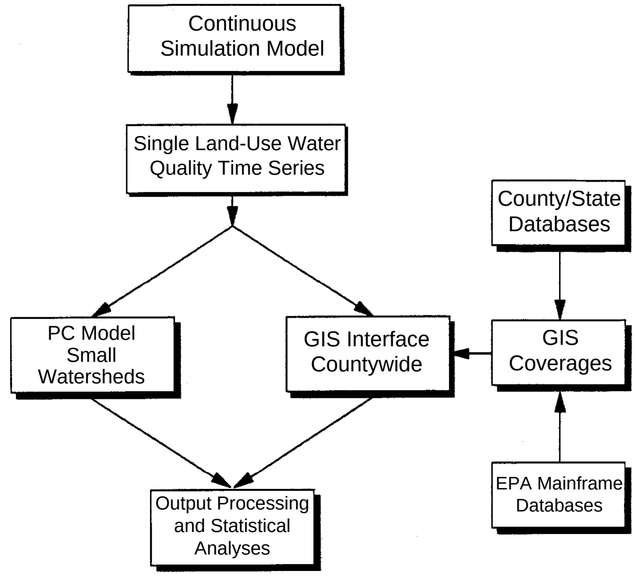


**Figure 1. Watershed modeling approach.**

Although SWMM was used for this application of GWSM, results from other continuous simulation models can also be included in the model. This modular approach enables increased simulation accuracy as calibrated models become available. Further, several models can be used within a single application, combining the strengths of each. For instance, SWMM could be used for urban areas, while HSPF could be applied to agricultural lands within a single study area.

## Input Data Requirements

GWSM requires both ARC/INFO vector coverages and continuous simulation model output for each land-use type modeled. Coverages include watershed boundaries and current land-use files. Input data for SWMM include parameters for the rainfall, temperature, and runoff blocks for each of the nine homogenous land-use basins.

## A Case Study: Collington Branch Watershed

Water resource managers face multiple questions on how best to manage stormwater on a regional, watershed, and subbasin scale. In Prince George's County, an area covering over 480 square miles, there are 41 watersheds of varying size and land-use distribution. The proximity of the county to the fast-growing metropolitan Washington, DC, area makes stormwater management a complex and pressing problem.

An assessment of the predominantly forested and agricultural Collington Branch watershed, covering approximately 14,820 acres and draining to the Western Branch and to the Patuxent River, was performed as a demonstration of the GWSM. Figure 2 is the watershed selection screen from the GWSM, including the land-use distribution for the Collington Branch watershed. This case study demonstrates how the GWSM can be applied using a three-step approach: 1) identify and target problem watersheds, 2) identify pollutant sources and characterize pollutants, and 3) conceptually identify control measures and evaluate future land-use changes.

### *Watershed Problem Identification and Targeting*

Often, the first questions that water resource managers ask are, How can problem watersheds be identified, and how do watersheds compare with each other in terms of pollutant loads and flows? GWSM enables the rapid analysis of the relative contributions of each watershed to the total load, performing a complete assessment and interpretation of the data within 10 minutes. The results

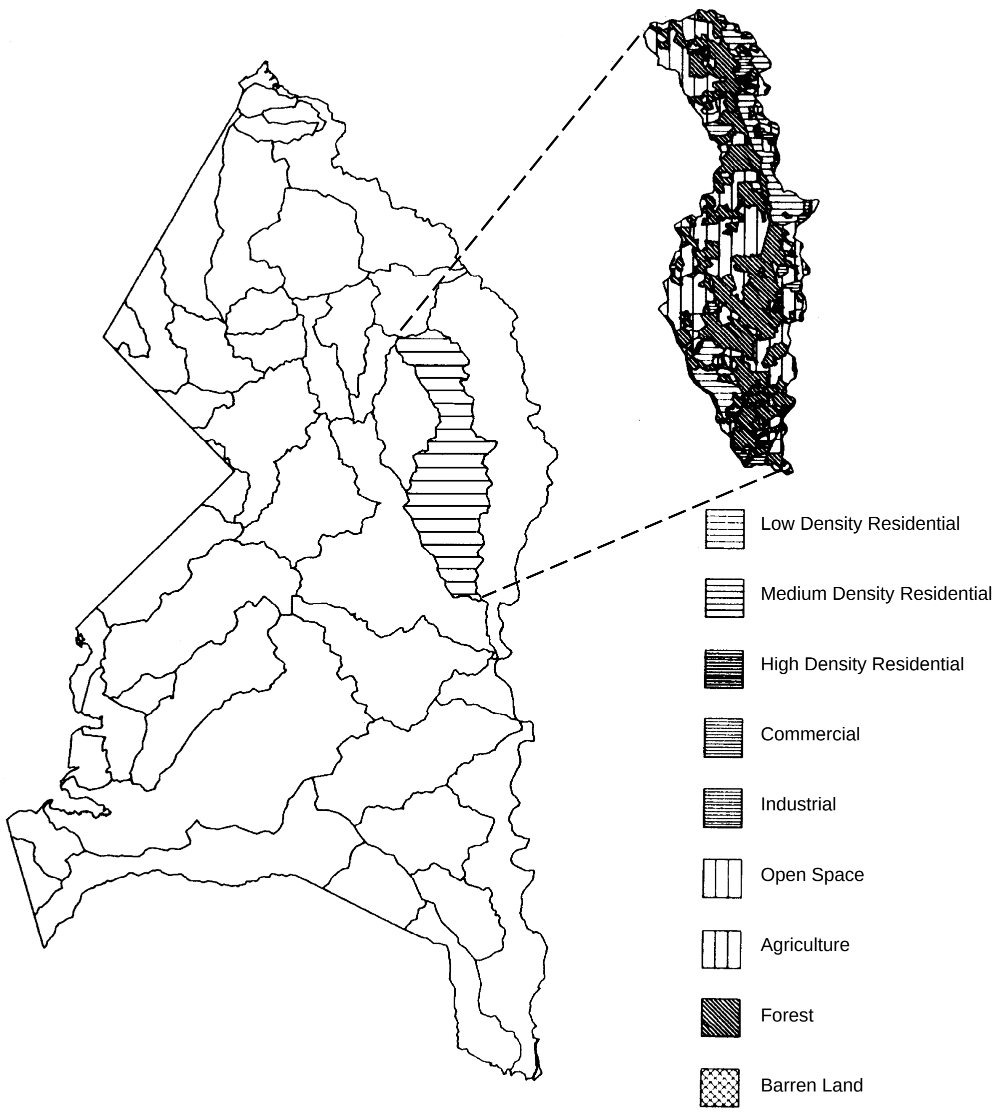


**Figure 2. Watershed selection screen for the Collington Branch watershed, including land-use distribution.**

include estimates of annual, mean monthly, and monthly loads for the watershed for 12 parameters. Each constituent may be viewed either as a percentage of the total load or in actual units (pounds or cubic feet). Figure 3 presents the graphical display from GWSM showing the total nitrogen load for the Collington Branch, illustrating the changes in loads due to climatic variability.

A comparison between two watersheds is easily performed to assess load and flow estimates and review results graphically. Multiple applications provide a rapid assessment of all the major watersheds in the county. This phase of the GWSM analysis provides information to answer the questions, Which are the likely water quality impacts, and how significant are they compared to other watersheds?

### *Identify Pollutant Sources and Characterize Pollutant of Concern*

Once problem watersheds are identified and targeted for further analysis, the water quality problems must be clearly defined. What are the sources of the pollutants of concern? An analysis of the pollutant contribution by land use is included in GWSM, calculating constituent load by land use for each of the 12 parameters. Figure 4 shows total nitrogen contributions for each land use in the Collington Branch, indicating that agricultural areas are the primary source. This provides important information for targeting control programs throughout the watershed. Characterizing the pollutant loads is an important issue for developing management programs. The following questions are answered at this phase: What pollutants are of primary concern? What are their sources and spatial and temporal characteristics? How do their loads vary seasonally and annually? What are the temporal variations between pollutants? To answer these questions, GWSM provides graphical displays of mean monthly, mean annual, and annual pollutant loads for each pollutant.

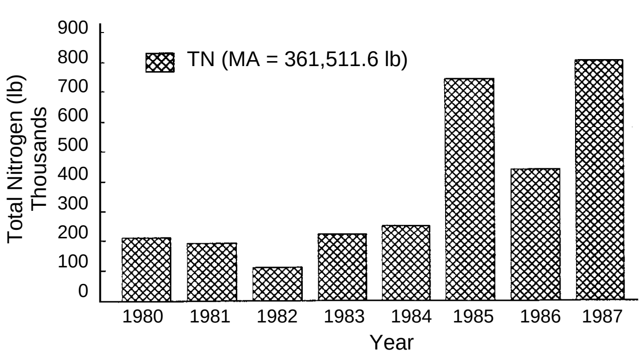


**Figure 3. Annual summary of total nitrogen load, Collington Branch watershed, illustrating changes in loads due to climatic variability.**

### *Management Screening*

In this phase, implementing the most cost-effective controls is addressed. To address control measures, the relationship between storm size, runoff volume, and pollutant load must be assessed. For example, what storm sizes contribute the largest pollutant loads, and which storm size should be targeted? The analytic routines in GWSM provide graphical answers to these questions. Figure 5 presents lead loads by storm size, indicating that targeting only a percentage of runoff will control over half of the total load. Figure 6 illustrates the rainfall/runoff characteristics of the watershed, with the majority of storms generating less than 0.05 in. of runoff. These estimates will vary by watershed and type of pollutant, but GWSM allows rapid analysis of each pollutant and multiple watersheds.

Management evaluation is done at both watershed- and site-specific levels. Over an entire watershed, what is the optimal control level for structural water quality facilities? GWSM includes a stormwater pond routine that calculates the pollutant mitigating effects of different

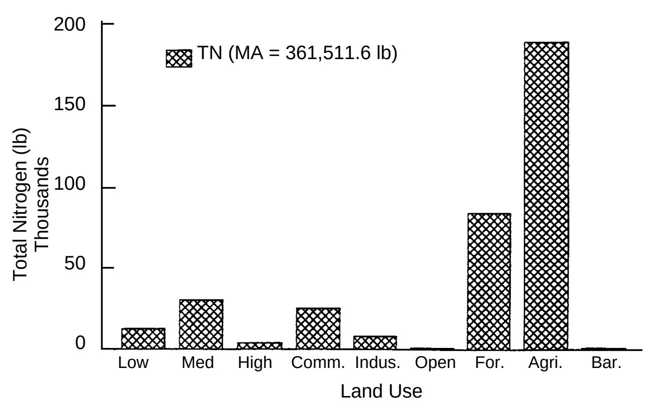


**Figure 4. Total nitrogen load by land use, Collington Branch watershed.**

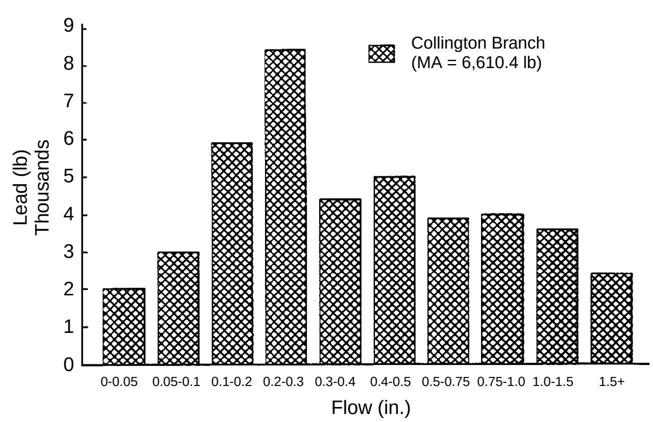


**Figure 5. Lead distribution by storm size, Collington Branch watershed.**

control levels and retention times. At a site-specific level, such as a proposed new subdivision, similar structures can also be evaluated to allow optimal design criteria to be selected. Figure 7 illustrates the phosphorus contribution for a simulated residential subdivision, and the pollutant reduction from a stormwater pond designed to control for 0.3 in. of runoff. As seen in Figure 7, the mean annual phosphorus load was reduced from 453 to 277 lb by the simulated structure.

Managers must address how future changes will affect water quality. On the watershed level, what will be the impact of urbanization on flow and pollutants loads? At the subbasin level, how will proposed projects change the runoff characteristics? Both land use scenarios can be evaluated in GWSM. On the watershed scale, the current land use can be interactively changed with a "point-and-click" menu. At the subbasin level, a user-defined basin may be modeled, with the land-use distribution entered into a pulldown menu. At both watershed and subbasin levels, once a land-use scenario is selected, GWSM calculates the anticipated pollution loads. The results can then be compared with preexisting conditions. The following questions are answered during the final phase of GWSM: How do pollutant loads relate to rainfall and runoff distribution and intensity?

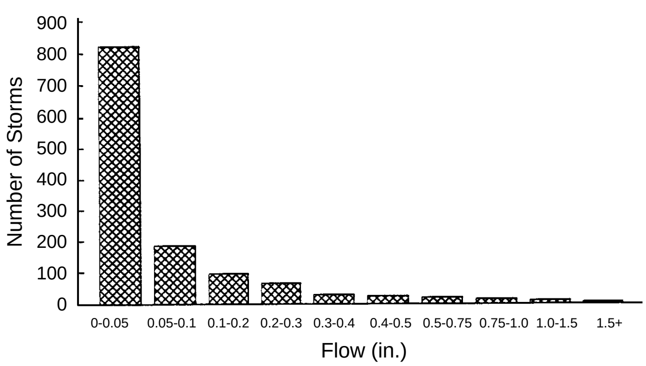


**Figure 6. Flow (frequency) distribution by storm size, Collington Branch watershed.**

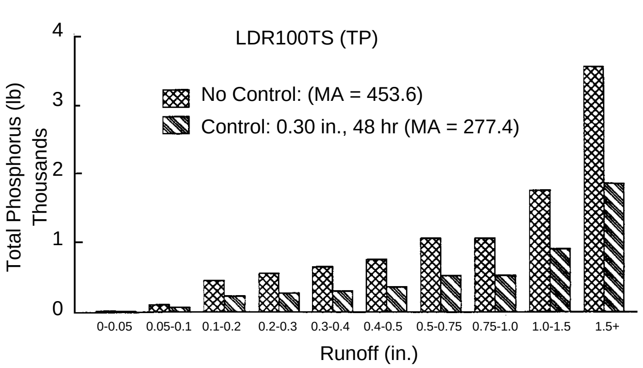


**Figure 7. Phosphorus contribution for a simulated residential subdivision with a stormwater pond designed to control for 0.3 in. of runoff.**

What is the optimal control level for structural practices? What are the likely impacts of future land-use changes on water quality?

## Stormwater Management: Future Model Applications

The NPDES stormwater permit regulations have created new challenges and opportunities for state, county, and city water resource programs. Water resource managers are faced with often conflicting stormwater management objectives and forced to make decisions that weigh the costs and benefits of each. For instance, water quality and flood control objectives do not always coincide. The design and management of regional stormwater ponds will vary depending on whether water quantity control or water quality control is the primary objective.

To address the complex array of stormwater issues, more sophisticated analytical tools and techniques are needed. Watershed models that effectively evaluate alternative scenarios and allow for optimization routines for differing management objectives are in demand. Integrating environmental data, such as wetland areas, bioassessment information, structural and nonstructural best management practice (BMP) optimization, and permit and monitoring information will be required in a user-friendly GIS package.

As the NPDES stormwater regulations are implemented at the county and local level, unique management programs will develop according to specific water quality and resource availability issues. As these programs take shape, GIS and GIS-based models and information management systems are likely to play larger roles in assessing problems and crafting solutions.

## Conclusions

The GWSM enabled the rapid assessment of Prince George's County's stormwater problem areas and the evaluation of control measures. GWSM was developed to support the development of the county's stormwater management program. The model incorporates the strengths of continuous simulation modeling with the spatial analysis techniques of GIS in an integrated system. Together, the GIS and data processing routines allow for further analysis and interpretation of time series data from the SWMM model. Combining continuous time series data with georeferenced watershed/land-use data allows for the further analysis and interpretation of the results. As additional data from monitoring both homogenous land-use basins and in-stream locations becomes available from the long-term monitoring program developed as part of the NPDES Part 2 permit, the accuracy of the model will increase.

As technologies for developing and evaluating stormwater programs increase in sophistication, the questions asked of water resource managers are likely to become more difficult. The GWSM will continue to develop to incorporate more functions designed to assist managers to make the best, most informed decisions.


## Acknowledgments

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# *Watershed Screening and Targeting Tool (WSTT)*

**Leslie L. Shoemaker and Mohammed Lahlou**
**Tetra Tech, Inc., Fairfax, Virginia**

## Abstract

Screening-level tools allow managers to understand, evaluate, and compare the water quality problems of watersheds so that they can be prioritized. The Watershed Screening and Targeting Tool (WSTT) makes it easier for watershed managers in federal, state, and local agencies to conduct these evaluations by providing access to the necessary data and information and facilitating the assessment itself. This prototype has been developed as a cooperative project for the U.S. Environmental Protection Agency (EPA) Region 4 and the Office of Wetlands, Oceans, and Watersheds in support of the Total Maximum Daily Load (TMDL) program.

The WSTT is an interactive, user-friendly, two-step evaluation and targeting process. The first step allows for preliminary screening based on multiple criteria. Each criterion can be compared with a default or user-defined reference value. Data from EPA mainframe databases allow the user to compare reference values with land-use and water quality observations from watersheds under consideration. The second level of targeting, comparative analysis, allows for a more detailed examination of watersheds. In addition, this analysis permits the user to include subjective weights and additional data to the targeting procedure. The algorithms for this targeting system are based on a hierarchical structure of objectives and criteria, where a set of up to seven criteria can be used to describe the comparison objectives. Although the analysis objectives are project specific, the procedures are developed to use either user-specified data or information from provided databases. Weights can be entered to give greater or lesser value to particular criteria. This paper presents examples of the application of these techniques to sample watersheds in Alabama.

## Introduction

Targeting of watersheds is used to allocate increasingly scarce water management resources for data collection, modeling studies, and management assessment, design, and construction. Water resource managers can use screening-level evaluations to help assess, compare, and prioritize the water quality problems of watersheds within their jurisdictions. The Watershed Screening and Targeting Tool (WSTT) makes it easier for watershed managers in federal, state, and local agencies to conduct these evaluations by providing easy access to the necessary data and facilitating targeting assessments. A prototype of WSTT has been developed that allows access to data for Alabama and Georgia. WSTT operates on a personal computer (286+) in a DOS environment.

WSTT provides an interactive, user-friendly, two-step evaluation and targeting process (Figure 1). The first allows for preliminary screening based on multiple criteria. Each criterion can be compared with a default or user-defined reference value. Data from U.S. Environmental Protection Agency (EPA) mainframe databases allow the user to compare reference values with land-use and water quality observations from watersheds under consideration. The second level of targeting, comparative analysis, allows for a more detailed examination of watersheds. In addition, this analysis permits the user to include subjective weights and additional data in the targeting procedure. The algorithms for this targeting system are based on a hierarchical structure of objectives and criteria, where a set of up to seven criteria can be used to describe the comparison objectives. Although the analysis objectives are project specific, the procedures are developed to use either user-specified data or information from provided databases. Weights can be entered to give greater or lesser value to particular criteria.

Watershed prioritization and targeting involve a multistep decision-making process using both technical criteria and subjective judgement. The use of formal targeting procedures throughout this process can assist in structuring the problem while taking into account all pertinent and site-specific concerns.

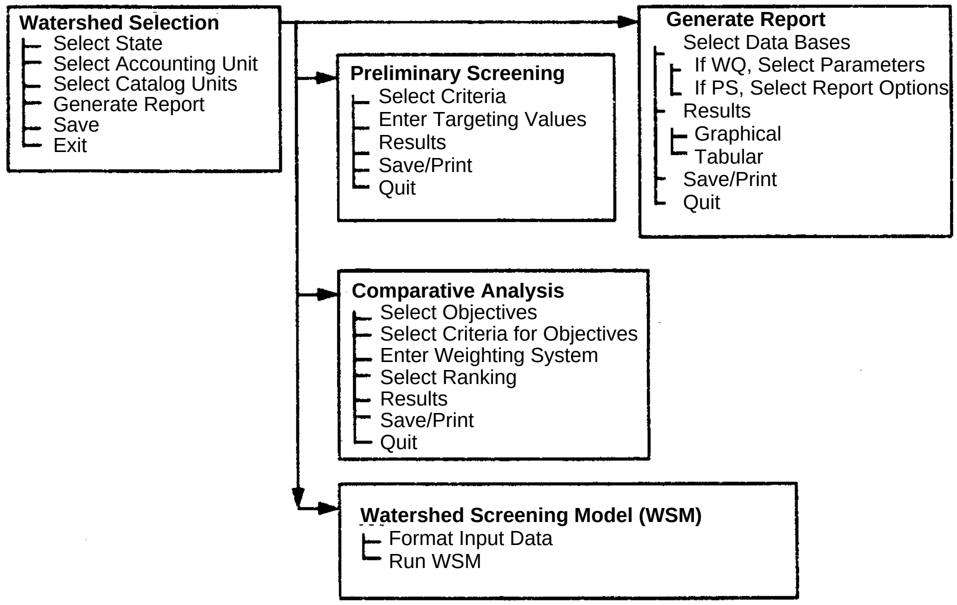


**Figure 1. Schematic of WSTT components.**

Multicriteria analysis techniques can aid in processing available information in a more structured framework, leading to a rational prioritization of watersheds. These procedures can be used in the Total Maximum Daily Load (TMDL) process to identify data sources, retrieve relevant water quality and watershed data, and analyze these data within a structured framework to determine which watersheds require management. The advantages of structured decision-making techniques—especially when dealing with numerous watersheds where the ranking in order of priority is not obvious *a priori*—include analysis directed toward the selection of pertinent decision criteria and identification of potential candidate watersheds; credibility of the selection process by the use of demonstrated and valid decision-making techniques; reductions in the cost and time for data collection and processing through a multiphase screening process; iterative evaluation of watersheds; and increased understanding of the various tradeoffs.

For the incorporation of targeting criteria and the generation of reports, WSTT is distributed with and relies on data that were selectively downloaded from EPA's mainframe computer. The databases that it uses include an accounting unit/catalog unit (CU) summary table, land use (U.S. Department of Agriculture Natural Resource Inventory summary of acres per land-use category), water quality (EPA STORET ambient water quality data summarized by CU for 50 parameters), reference levels (based on EPA water quality criteria), water supplies (number, flow, location, and type), point sources (number, flow, location, and type), and water bodies (number and size). These data, always available to the public, have traditionally been difficult to access without familiarity with EPA's mainframe. Through WSTT, these data are readily accessible. Using these databases, WSTT can generate reports, in table or graph form, on land use, water quality, water supplies, impoundments, and point source facilities in each of the selected areas.

The data that are distributed with WSTT can also be used to prepare preliminary data input files for a watershed screening model (WSM) which, for this prototype version, can be run for CUs within Georgia and Alabama. The watershed screening methodology permits simple watershed assessments that predict daily runoff, streamflow, erosion, sediment load, and nutrient washoff. The WSM relies on observed precipitation and temperature data from local meteorologic stations, municipal point source load estimations from pollutant concentrations in the literature, and nonpoint source loading functions for selected land uses based on literature values. Users can readily modify or revise the input data to reflect site-specific conditions. Output data from the model simulations can be used to augment information provided by the other databases.

## Review of Potential Targeting Procedures

Most multicriteria decision techniques with potential application to the prioritization and targeting process can be grouped into three categories:

- *Sequential elimination:* Techniques to eliminate watersheds that do not show any need for controls.
- *Dominance theory:* Techniques to eliminate inferior or dominated watersheds that demonstrate a need for

pollution control but do not present a character of relative urgency.

- *Ranking procedures:* Techniques to prioritize remaining watersheds.

## *Sequential Elimination*

The first group of analytical procedures target nonpriority watersheds or the nonfeasible set of watersheds. These procedures are typically referred to as sequential elimination techniques. Each watershed is compared with a hypothetical watershed using an amalgamation of standards and criteria. Watersheds that are better than the hypothetical watershed form the nonfeasible set and can be eliminated from further analysis. These techniques provide a preliminary filtering system to ensure the legitimate acceptability of the remaining set of watersheds. Sequential elimination techniques do not differentiate on the basis of relative importance, only on the ability to satisfy a condition of preset limits. Four relevant sequential elimination techniques, available for application in the prioritization process, include the conjunctive approach, the disjunctive approach, the lexicographic approach, and the compensatory approach (1).

The conjunctive approach screens out watersheds by establishing minimum cutoff levels for each discriminating criteria. Depending on the type of criterion and its method of measurement, the constraint or “cutoff level” is defined as either a categorical exclusionary or inclusionary limit. The application of a conjunctive scheme relates the decision criteria and their constraint with the logical “and” so that all constraints must be satisfied for a watershed to be eliminated from further consideration. Evaluation scales do not have to be homogeneous across criteria and can include logical, numeric, or natural scales. Because decision criteria and the set of watersheds are independent, each watershed is compared individually with a hypothetical set of constraints rather than with other watersheds. In general, decision criteria in the conjunctive approach should be carefully selected to focus on criteria with a strict regulatory requirement and technical constraints that cannot be relaxed or are not subject to tradeoffs.

The disjunctive approach is similar to the conjunctive scheme, but it requires that only one criterion be satisfied for a watershed to be eliminated from further consideration. Because this process is characterized by the logical relation “or,” problem formulation must be defined in terms of the level of substitutions among the selected decision criteria.

Lexicographic screening differs from the previous techniques in that the value of each criterion is compared across watersheds (2). The criteria are first ordered in terms of their relative importance, and watersheds are then screened, starting with the most important criteria. Watersheds that pass this preliminary test are screened with the next highest ranked criteria until either all criteria are evaluated or the number of watersheds selected for further analysis is sufficiently reduced.

Compensatory analysis is a more elaborate form of conjunctive and disjunctive screening and deals primarily with preferential constraints where the cutoff levels are set by the objectives rather than by the criteria themselves (3). The analysis develops constraints on selected objectives that are represented in the decision problem by a group of two or more criteria. For each identified objective, the corresponding criteria are combined into a discriminating model expressing the degree to which each criterion achieves the objective. The discrimination process can be inclusionary, exclusionary, or both, depending on the screening model.

## *Dominance Theory*

The second group of analytical tools with potential for application in the watershed prioritization and targeting process consist of techniques developed from the dominance approach. This approach serves to identify poorer watersheds rather than rank them completely. In this case, when the first watershed that has criterion values at least as poor as those of a second, as well as one or more values that are poorer, the first watershed will be selected for further analysis rather than the second. The first watershed is said to dominate the second. These techniques add some capability of determining which watersheds are worse than others beyond the simple comparisons offered by the sequential elimination schemes. Although several techniques have been developed based on this decision rule, their application to discrete decision space, such as watershed targeting applications, may not be effective in eliminating many watersheds. Among these techniques are the noninferior curve technique, the indifference map technique, and fuzzy outranking approaches.

The noninferior curve technique uses the distribution of the feasible set of watersheds within the decision space to identify inferior and noninferior sets (4). The curve defines the level of tradeoff between decision criteria where any incremental improvement in one criterion results in a balanced incremental decrease in other criteria. Application of this technique may require excessive computational time and professional training for interpretation of the results (5).

The indifference map technique relies on the representation of the preference structure to determine the family of indifference curves (6). An indifference curve represents points in the decision space for which the preference is equivalent among all criteria. This approach can be used in combination with the noninferior curve technique. Theoretically, if the one indifference curve tangent to the noninferior curve can be located, then watersheds lying farthest from the point of tangency form the set with the highest priority for controls.

Outranking techniques analyze sets of watersheds to derive binary relationships on the set rather than a function from this set to the real numbers, as in the case of the classical theory of decision analysis. This binary relationship also differs from classical decision analysis in the sense that it does not necessarily require a strict transitivity condition (7, 8). Outranking procedures can be used to select one and only one watershed, a set of acceptable watersheds, or a cluster of watersheds in an ordered sequence of indifference classes ranging from best to worst.

### *Ranking Procedures*

The third group of analytical decision techniques ranks the set of watersheds under consideration. Several algorithms with potential application to discrete situations include utility theory, compromise programming and displaced ideal techniques, cooperative game theory, and the analytic hierarchy process.

Decision techniques developed based on the theory of utilities assign a utility function to each decision criterion, then compute the expected utility for each watershed using either an additive or multiplicative model (9). Watersheds that maximize the expected utilities may be eliminated from further analysis, and those with low ranking values form the set to be considered. The difficulties associated with application of the utility models reside in the development of representative utility functions for each criterion and the insurance that all criteria satisfy both preference and utility independence axioms. A utility function refers to a mapping of the values in the range of natural criteria scale to a bounded cardinal-worth scale reflecting the preference structures associated with that criteria as perceived by the decision-maker(s).

Compromise programming techniques have been applied extensively to water resources projects. These techniques attempt to identify watersheds that approach an ideal case (10), assuming that the watershed located the closest to the ideal watershed in the decision space can be eliminated from further consideration. The computation algorithms rank watersheds based on the normalized distance between each watershed and this ideal point. This approach can also be applied to identify watersheds that are the closest to an anti-ideal point using a similar minimization scheme.

Cooperative game theory is a representation of a conflict situation based on the general concepts of rational behavior. Optimization of a set is sought by well-informed decision-makers with conflicting objectives who are aware of their preference structure. The objective of each participant in the game is to identify solutions that are high on the preference scale. A generic algorithm based on this theory for an n-person game was developed by Harsanyi (11). This algorithm was generalized for a regional ground-water pollution problem (12) and for the analysis of wastewater management alternatives (13).

The analytic hierarchy process was developed in an effort to expand the classical decision models to include subjective analysis of multilevel or hierarchical systems (14, 15). The process consists of decomposing the decision problem into smaller subproblems, analyzing each subproblem individually, and then recomposing the results to reach a complete ranking of the set of watersheds considered. It relies strongly on the structuring of the decision problem into an intuitively logical hierarchy of objectives and criteria. The hierarchical structures express the factual relationships between the decision elements (objectives, criteria, and alternatives). This decision process parallels the principles of analytical thinking (16): constructing hierarchies, establishing priorities, and logical consistency.

## Targeting Techniques in WSTT

The review of decision analysis techniques, briefly described above, provided the background for the development of the targeting tools used in the WSTT. The development of decision-making techniques for watershed prioritization and targeting was based on the following:

- Ability to perform a multicriteria analysis.
- Applicability to discrete situations with a limited number of watersheds.
- Applicability to selecting the worst watersheds rather than the preferred conditions, as is the case in most decision situations for TMDLs or watershed management.
- Flexibility of problem structuring, data processing, and the ability to decompose the problem into smaller and more homogeneous components.
- Stability of the final ranking using simple scaling procedures.
- Ease of interpreting the rankings.
- Ability to perform sensitivity analysis and consistency testing of the value judgment.

These considerations led to the development of a two-step targeting approach consisting of both a preliminary screening and a formal comparative analysis. A test watershed is used for illustrating examples of the two types of screening techniques (Figure 2).

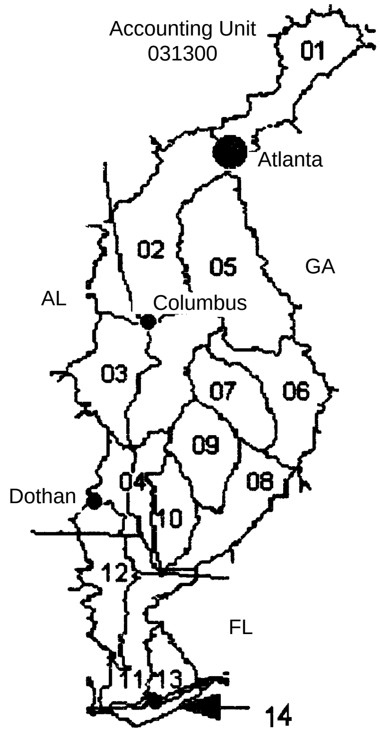


**Figure 2. Watersheds selected for preliminary screening.**

## *Preliminary Screening Analysis*

The screening level analysis of watersheds at a regional or accounting unit scale is designed to help users understand what the water quality conditions are in each watershed and how the factors governing quality vary from one watershed to the next. The advantage of this procedure is its ability to operate under the WSTT environment, using automatically retrieved values for the desired decision criteria, and iteratively screen out watersheds that do not represent a significant water quality problem.

The screening algorithm used in WSTT consists of a sequential elimination scheme adapted from the conjunctive approach described in the previous section. The objective of this process is to identify watersheds that do not represent a significant water quality problem and consequently reduce the set of watersheds to a workable number. The significance of the water quality problem is, however, indirectly introduced into the analysis through the selection of screening criteria indicative of the problem under consideration and the magnitude of each criterion cutoff level. Figure 3 illustrates this process using a single water quality criterion, and Figure 4 presents the case of a two-criteria screening. Based on the sample cutoff limit shown in Figure 3, six watersheds (1, 2, 3, 4, 5, and 13) would be selected for further analysis. In Figure 4, two criteria are examined. In this case, both acres of urban land and $BOD_5$ concentrations are selected for examination. Values outside the upper limits for either of the two criteria would be selected for

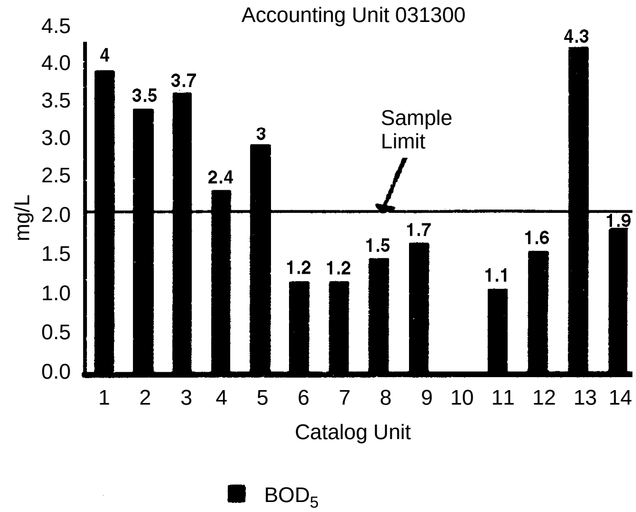


**Figure 3. Preliminary screening example with one criterion.**

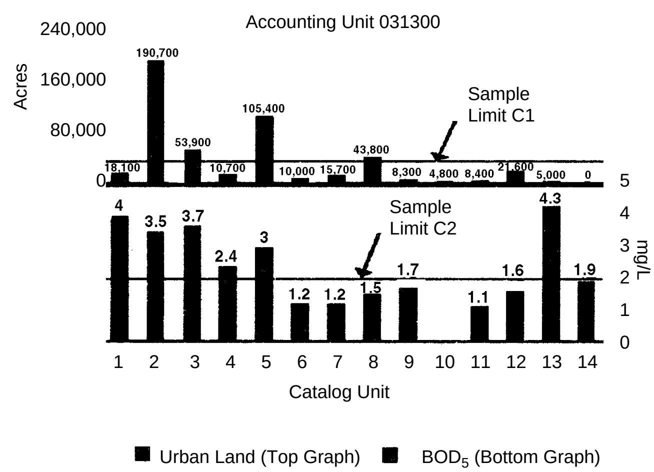


**Figure 4. Preliminary screening example with two criteria.**

further examination. In this case, seven watersheds (1, 2, 3, 4, 5, 8, and 13) would be selected. The user can select the cutoff limits in an iterative fashion to examine the differences between the watersheds. Multiple criteria can be selected for evaluation, depending on data availability and watershed characteristics. This provides a quick and easy approach for preliminary evaluation of the differences between the watersheds selected for examination.

For a multidimensional problem, each criterion is defined in terms of a cutoff limit representing a vector of threshold values. Depending on the type of criterion and its measurement scale, each value in this vector may either represent an upper or a lower limit. Examples of criteria with an upper limit are water quality parameters for which the cutoff limit represents a concentration that should not be exceeded. On the other hand, criteria with a lower limit include those with ascending scales in which the higher values are better, such as in the case of dissolved oxygen concentration.

The watershed screening level analysis in WSTT allows users to retrieve screening criteria and their values automatically from available, preprocessed databases. When the criteria represent water quality parameters, watershed rating with respect to each criterion can be expressed in terms of a mean value, a median, or a quartile. Multiple databases can be accessed sequentially. Access to the water quality and land-use databases is enabled at the present time. Cutoff limits are user specified and can be modified in an iterative scheme by either relaxing the criteria's cutoff limit and consequently decreasing the set of selected watersheds or by making them more stringent. Watersheds eliminated during this screening level analysis can still be considered in the comparative analysis phase. The output of this algorithm generates a list of watersheds that do not satisfy the criteria's cutoff levels. For these watersheds, the corresponding input data (payoff-matrix) can be accessed through the reporting option of the WSTT. Watersheds that satisfied all user-specified constraints are also tabulated. As noted earlier, the screening analysis does not take into consideration the relative differences in the exceedence of the observations beyond the upper limit. For examination of the relative importance and actual ranking of the watersheds, the comparative analysis technique is used.

## *Comparative Analysis in WSTT*

The objective of the comparative analysis is to provide a system that captures both the importance of the selection objectives and that of the criteria describing these objectives. Comparative analysis can provide a complete ordering of watersheds. The process requires that the targeting problem be formulated in terms of a decision situation and that judgement values be incorporated into each phase of analysis. At this level of analysis, additional measurable and subjective criteria are usually incorporated into the analysis; therefore, the algorithm provides a logical scaling system to evaluate the importance of these objectives on a common basis. The algorithm also incorporates a mathematical framework to amalgamate the value judgement and the watershed observations with respect to each criterion or objective in terms of a ranking index.

Four subroutines incorporated in the development of the comparative analysis algorithm in the WSTT are described below.

### Structuring of the Targeting Problem

The formulation of watershed prioritization problems in WSTT consists of a multilevel hierarchical structuring of the selection objectives, the decision criteria, and the alternative watersheds. This formulation separates the selection problem into several smaller and homogeneous subproblems which can be easily compared. Figure 5 illustrates a generic representation of a clustered hierarchy in which the project is decomposed into a set of simple and smaller subprojects. Each subproject can be analyzed separately, and the results can be reintegrated to obtained an overall ranking of the watersheds.

### Value Judgment

The decision-maker's value judgment is introduced in terms of the importance weight coefficients of the objectives and criteria. The derivation of criterion importance weights proceeds according to the hierarchical structure of the decision problem, starting from the higher level objectives. This routine takes the decision-maker through a series of paired comparisons cluster by cluster in the order shown by the roman numerals in Figure 5. For each paired comparison between two criteria, the decision-maker defines which criterion of the pair is more important and determines the magnitude of the importance using the integer ratio scale presented in Table 1. The magnitude of importance is not the desired importance weight but rather a measure of a pairwise ratio defined as follows:

$$a_{ij} = \frac{W_i}{W_j} \qquad \text{(Eq. 1)}$$

where a represents the ratio of importance weight W of criterion i over that of criterion j.

The use of the ratio scale defined in Table 1 generates a square, positive, and reciprocal matrix in which the importance weight coefficients consist of the entries of the eigenvector corresponding to the maximum eigenvalue of the this matrix. The characteristics of the resulting comparison matrix are summarized as follows:

$$a_{ij} = \frac{1}{a_{ji}} \qquad \text{(Eq. 2)}$$

for all i and j;

$$a_{ii} = 1 \qquad \text{(Eq. 3)}$$

for all i=1 to n where n is the number of criteria; and

$$a_{ik} = a_{ij} + a_{ik} \qquad \text{(Eq. 4)}$$

The rationale for determining the eigenvector corresponding to the maximum eigenvalue as the importance weight coefficient vector derives naturally from the type of scale used in the pairwise comparisons and the as-

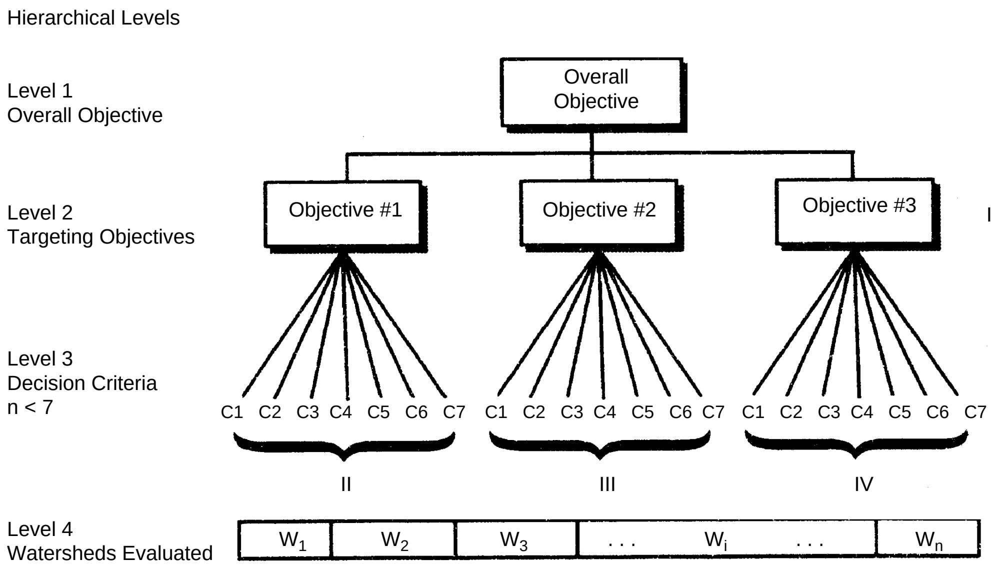


**Figure 5. Generic representation of the watershed targeting problem in WSTT.**

**Table 1. Evaluation Scale Developed by Saaty (14) for Use in the Analytic Hierarchy Process**

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective. |
| 3 | Weak importance of one over another | Experience and judgment slightly favor one activity over another. |
| 5 | Essential of strong importance | Experience and judgment strongly favor one activity over another. |
| 7 | Demonstrated importance | An activity is strongly favored, and its dominance is demonstrated in practice. |
| 9 | Absolute importance | The evidence favoring one activity over another is of the highest possible order of affirmation. |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgments | Compromise is needed. |
| Reciprocal of above nonzero | If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i. | |
| Rational | Ratio arising from the scale | Consistency is forced by obtaining n numerical values to span the matrix. |

sociated matrix theory used in solving nonlinear systems, expressed in matrix form as

$$A \cdot W = n \cdot W, \qquad \text{(Eq. 5)}$$

where A is the comparison matrix with n entries, n is the number of criteria, and W is the vector of importance weight coefficients. The solution of the above eigenvalue problem for each cluster in the order shown in Figure 5 provides a partial weight coefficient for each criterion. The overall weight can be derived by multiplying the partial weight of the dominant objective by that of the criteria:

$$W_i = W_p\,(objective) \cdot W_p(criteria_i). \qquad \text{(Eq. 6)}$$

## Consistency of the Preference Structure

When dealing with large numbers of objectives and criteria, the preference structure tends to lose its transitive character. As intransitive comparisons are introduced, the resulting matrices become less consistent, and the importance weight coefficients may not represent the true preference structure.

For a perfectly consistent positive reciprocal matrix, the maximum eigenvalue should equal the order of the matrix. This suggests that the remaining eigenvalues are equal to zero. As small inconsistencies are introduced into the matrix because of intransitive judgements, they lead to very small perturbations in the original set of eigenvalues. This represents the fundamental theory of consistency measurement in positive reciprocal matrices (14). The more the maximum eigenvalue deviates from that of a consistent matrix, the less consistent the pairwise comparisons are. A consistency index developed by Saaty (14) was introduced into the targeting subprogram in WSTT to indicate the degree of consistency at the end of each series of pairwise comparisons. A consistency index of 0.0 indicates a perfect consistency, and a value of 1.0 indicates a fully inconsistent matrix. Because of the use of an integer scale in addition to the nonlinearity of certain subjective judgments, a slight nonconsistency in developing importance weight coefficients is common. In fact, a fully consistent comparison is not required to reach the desired accuracy. Analysis of the sensitivity of eigenvalue solution shows that matrices with a consistency ratio of up to 0.1 are acceptable (17).

### Ranking of Watersheds

The hierarchic representation of the watershed targeting process is a logical structure for integrating the decision elements into a single problem and deriving the selection priorities defined in terms of objectives, criteria, and their respective weight coefficients. To derive the overall ranking of the watersheds, a simplified form of the additive utility model is used. This model is described in much of the relevant literature as the best known of the multiattribute utility functions because of its relevance to a wide range of decision problems, its stability in ranking alternatives, and its simplicity of application. This model is also used in most index calculations. Its generic expression when applied to a hierarchic problem takes the following form:

$$U_i = \sum_{j=1}^{N} W_j \cdot \sum_{k=1}^{M} W_k \cdot V_k, \qquad \text{(Eq. 7)}$$

where

W = weight coefficient
N = number of objectives
M = number of criteria under each objective
U = ranking of watershed i
V = measurable value of lower level criteria

This model uses normalized values of the criteria in an ascending scale, meaning that the higher values are better. The ranking is therefore performed on a descending scale so that watersheds with the lowest scores are identified as the priority watersheds.

The results of a sample application are shown in Table 2 below. For illustration purposes, a comparative analysis was applied, using WSTT, to six watersheds in Alabama. Three criteria were selected for examination—BOD5, ammonia, and iron—based on the 85th percentile of all data available on STORET since 1980. The values used for the comparative analysis are shown first. Three types of weights are shown: equal weights and two variable options. The final section of Table 2 shows how the changes in weights affect the resulting ranking of the watersheds. The ability to adjust weights and test a variety of user- and system-provided criteria allows for a wide range of flexibility in the assessment of watershed ranks. Users can thereby incorporate best professional judgement and local knowledge into the targeting procedure in a systematic fashion.

**Table 2. Description of Comparative Analysis Application**

**Values Used for Comparative Analysis (Payoff Matrix)**

| Catalog Unit | Criterion 1 $BOD_5$ (mg/L) | Criterion 2 $NH_4$ as N (mg/L) | Criterion 3 Fe (μg/L) |
|---|---|---|---|
| 0313001 | 4.0 | 0.27 | 1,100 |
| 0313002 | 3.5 | 0.62 | 1,600 |
| 0313003 | 3.7 | 0.30 | 315 |
| 0313004 | 2.4 | 0.14 | 680 |
| 0313005 | 3.0 | 0.66 | 2,900 |
| 0313013 | 4.3 | 0.16 | 370 |

**Calculated Importance Weight Coefficients**

| Criteria | Equal | Variable 1 | Variable 2 |
|---|---|---|---|
| 1 ($BOD_5$) | 0.333 | 0.122 | 0.637 |
| 2 ($NH_4$ as N) | 0.333 | 0.648 | 0.258 |
| 3 (Fe) | 0.333 | 0.230 | 0.105 |

**Final Watershed Ranking**

| Catalog Unit | Equal | Variable 1 | Variable 2 |
|---|---|---|---|
| 0313001 | 3 | 3 | 3 |
| 0313002 | 4 | 2 | 1 |
| 0313003 | 5 | 4 | 5 |
| 0313004 | 6 | 6 | 6 |
| 0313005 | 1 | 1 | 4 |
| 0313013 | 4 | 5 | 2 |

Application of the comparative analysis requires users to evaluate which criteria are relevant and significant to the local watershed conditions. Often, application will be constrained by the availability of water quality sampling information or other data. Consideration should also be given to possible dependence between two criteria selected. Criteria should be independent for accurate assessment of watershed ranking.

## Conclusions

The WSTT program and associated databases provide watershed managers with the tools to effectively target and assess watersheds on a broad scale. The two levels of targeting tools included with the WSTT allow for a range of targeting applications—from simple to sophisticated—depending on project needs. The incorporation of the comparative targeting tool provides the valuable addition of subjective judgement and user-defined parameters to the decision-making structure. This powerful algorithm allows managers to refine decision-making criteria and evaluate multiple and often conflicting objectives. The incorporation of targeting tools and databases into a user-friendly PC environment can make these powerful techniques convenient and accessible to a wide range of water resources professionals.

## Acknowledgments

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# *Hydrocarbon Hotspots in the Urban Landscape*

**Thomas Schueler and David Shepp**
**Department of Environmental Programs,**
**Metropolitan Washington Council of Governments, Washington, DC**

## Abstract

This paper reports on a monitoring study that compared hydrocarbon, polycyclic aromatic hydrocarbons (PAHs) and trace metal levels in stormwater runoff captured within standard oilgrit separators (OGSs) serving five automotive-related land uses in the Maryland Piedmont. Composite priority pollutant scans and trace metal samples were collected from the pools and the trapped sediments of 17 OGSs serving gas stations, convenience commercial, commuter parking lots, streets, and residential townhouse parking lots. Previous studies indicated that OGSs were not effective in trapping sediments over the long term, based on sediment accumulation rates over time. Oily sediments, however, were retained over a short term, making the OGS sites useful sampling ports to characterize differences in hydrocarbon and toxic levels in small, automotive-related land uses.

Gas stations had significantly higher hydrocarbon, total organic carbon, and metal levels than all other sites in both the water column and the sediments. Convenience commercial and commuter parking lots had moderate levels of contamination, with the lowest levels recorded for streets and residential townhouse parking lots. Mean hydrocarbon concentrations of 22 mg/L and 18,155 mg/kg were recorded for the water column and the sediments at gas station OGS sites. The priority pollutant scan identified 37 potentially toxic compounds in the sediments and 19 in the pools of gas station OGS sites. This can be compared with non-gas-station sites, which had 29 and 7 toxics in the sediment and water column, respectively. Some of the gas station priority pollutants included naphthalene, phenanthrene, pyrene, toluene, xylene, chrysene, benzene, phenols, acetone, and numerous trace metals.

The source of these pollutants appears to be spillage or leakage of oil, gas, antifreeze, lubricating fluids, cleaning agents, and other automotive-related compounds. The study suggests that numerous "hotspots" exist in the urban landscape that generate significant hydrocarbon and PAH loadings, particularly where vehicles are fueled, serviced, and parked for extended periods. Preliminary computations suggest a possible link between these hotspots and sediment PAH contamination of a local estuary.

## Introduction

Over the past decade, nearly one thousand oil grit separators (OGSs) have been installed in the metropolitan Washington area to treat urban stormwater runoff from small drainage areas. These structures consist of two precast chambers connected to the storm drain system (Figure 1). The first chamber is termed the grit chamber and is used to trap coarse sediments. The second chamber, termed the oil chamber, is used to temporarily trap oil and grease borne in urban runoff so that they may ultimately adsorb to suspended sediments and settle to the bottom of the chamber.

Most OGSs control runoff from highly impervious sites of an acre or less and have a storage volume of 0.06 to 0.12 in. of runoff, depending on the local design. As such, OGSs were never expected to achieve high rates of pollutant removal (1). Rather, they are intended to control hydrocarbons, floatables, and coarse sediments from small parking lots that cannot normally be served by other, more effective best management practices.

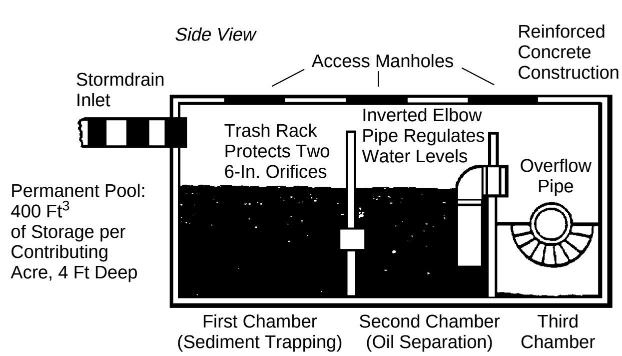


**Figure 1. Schematic diagram of an OGS (1).**

From a monitoring standpoint, OGSs are interesting in that they act as a very useful and standardized sampling port to extract runoff samples from very small areas of differing automotive land use. It was hypothesized that hydrocarbon and trace metal levels might be greater at sites where vehicles were parked, serviced, or fueled. These potential "hotspots" had never been systematically monitored in the metropolitan Washington area before.

## Methods

A two-tiered monitoring strategy was employed to test the effectiveness of OGS systems and to detect hydrocarbon hotspots. In the first tier of sampling, 110 OGS systems were surveyed to determine their general characteristics in the field. Each structure was sampled for the mass and particle size distribution of trapped sediments, land use, age, maintenance history, secchi depth, and other engineering parameters (2).

The emphasis on the second tier of sampling was to characterize the range of pool and sediment quality found within OGS and related systems. Nineteen of the Tier 1 sites were selected for additional detailed sampling of the quality of pool water and trapped sediments. The sites were grouped into five land-use categories: townhouse parking lots, streets, all-day parking lots, gas stations, and convenience store parking lots. Sediment and pool samples were collected from each chamber and were subsequently analyzed for nutrients, soluble and extractable metals, total organic carbon (TOC), and total hydrocarbons.

In addition, six priority pollutant scans were conducted based on composite sediment and pool water samples from gas station sites, non-gas-station sites, and all five land-use sites combined. The samples were analyzed for the presence of 128 compounds outlined in the U.S. Environmental Protection Agency's (EPA's) priority pollutant list. A complete description of the sampling and analytical protocol is contained in Schueler and Shepp (3).

## Results

### *Retention of Sediments in OGS*

The field surveys indicated that OGS systems had poor retention characteristics. The average wet volume of trapped sediments in 110 OGSs was 11.2 ft$^3$, with an average sediment depth of only 2 in. If OGS systems were highly retentive, the mass of trapped sediments would be expected to increase with age. No such relationship was evident, however, in the 110 OGSs surveyed (Figure 2), suggesting that frequent scour and resuspension occur.

Monthly sampling of sediment depths in individual OGS systems revealed sharp fluctuations in depth over time (Figure 3), with up to a 50-percent decrease in sediment depths recorded in a single month. Dye tests indicated pool residence times of less than 30 min during storms. Consequently, it is thought that the mass of trapped sediments contained within an OGS at any given point represents only a temporary accumulation of pollutants.

### *General Characteristics of OGS Systems*

Trapped sediments within OGSs were coarse-grained, highly organic, oily in appearance, and interlaced with litter and debris. Sediments were also quite soupy; only 45 percent total mass of sediment existed as dry weight. The proportion of volatile suspended solids, a measure of the general organic content of the sediments, averaged 15 percent of total mass.

OGS pools frequently had a thin oil sheen or surface scum, and oil stains were present on the chamber walls. Despite the sheen, the pool water was relatively transparent, with an average secchi depth of 14 to 22 in. Floatable trash was present in low to moderate quantities.

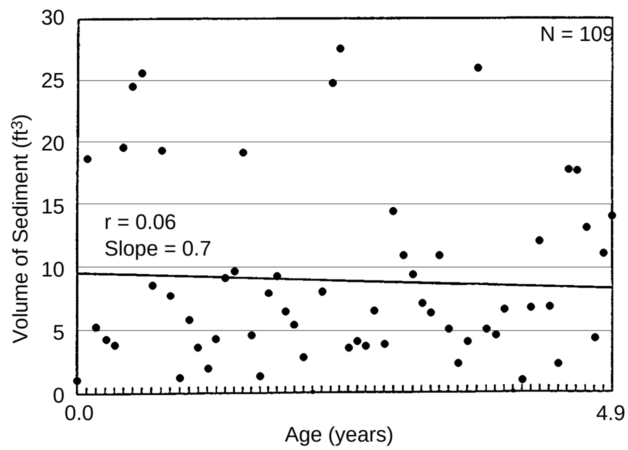


**Figure 2. Relationship of OGS age and volume of trapped sediments (2).**

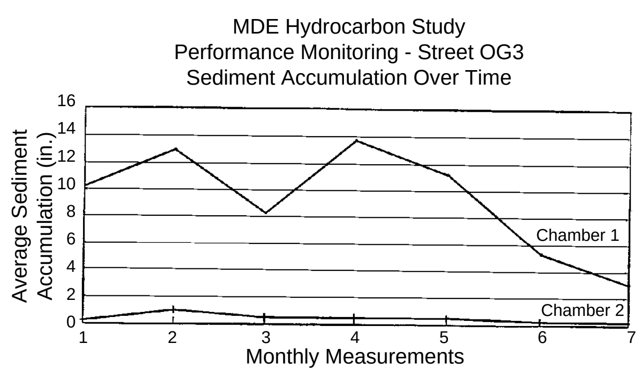


**Figure 3. Monthly change in depth in OGS (1).**

**Table 1. Characterization of Pollutant Concentrations in the OGS Water Column: Effect of Land-Use Condition (Mean Values)**

| Sampled Parameter | All-Day Parking (N = 8) | Convenience Commercial (N = 6) | Gas Stations (N = 7) | Streets (N = 6) | Townhouse/ Garden Apartments (N = 6) |
|---|---|---|---|---|---|
| OP (mg/L) | 0.23 | 0.16 | 0.11 | ND | 0.11 |
| TP (mg/L) | 0.30 | 0.50 | 0.53 | 0.06 | 0.19 |
| $NH_3$-N (mg/L) | 0.20 | 1.58 | 0.11 | 0.19 | 0.20 |
| TKN (mg/L) | 1.18 | 4.94 | 2.5 | 0.84 | 1.00 |
| OX-N (mg/L) | 0.65 | 0.01 | 0.21 | 0.92 | 0.17 |
| TOC (mg/L) | 20.60 | 26.80 | 95.51 | 9.91 | 15.75 |
| Hydrocarbons (mg/L) | 15.40 | 10.93 | 21.97 | 2.86 | 2.38 |
| TSS (mg/L) | 4.74 | 5.70 | — | 9.60 | 7.07 |
| ECD (μg/L) | 6.45 | 7.92[a] | 15.29[a] | ND | ND |
| SCD (μg/L) | 3.40[a] | ND | 6.34[a] | ND | 10.34[a] |
| ECR (μg/L) | 5.37 | 13.85 | 17.63[a] | 5.52[a] | ND |
| SCR (μg/L) | ND | ND | 6.40[a] | ND | 4.79[a] |
| ECU (μg/L) | 11.61 | 22.11 | 112.63 | 9.50[a] | 3.62 |
| SCU (μg/L) | 8.22[a] | ND | 25.64 | ND | 2.40 |
| EPB (μg/L) | 13.42 | 28.87 | 162.38 | 8.23 | ND |
| SPB (μg/L) | 8.10[a] | ND | 26.90[a] | ND | ND |
| EZN (μg/L) | 190.00 | 201.00 | 554.00 | 92.00 | NA |
| SZN (μg/L) | 106.70 | 43.70 | 471.00 | 69.00 | 59.00 |

[a]Mean is for all observations in which the indicated parameter was actually detected.
ND = not detected; NA = not applicable.

OP = ortho phosphate phosphorus
TP = total phosphorus
NH3-N = ammonia nitrogen
TKN = total Kjeldahl nitrogen
OX-N = oxidized nitrogen
TOC = total organic carbon
Hydrocarbons = total hydrocarbons
TSS = total suspended solids
ECD = extractable cadmium
SCD = soluble cadmium
ECR = extractable chromium
SCR = soluble chromium
ECU = extractable copper
SCU = soluble copper
EPB = extractable lead
SPB = soluble lead
EZN = extractable zinc
SZN = soluble zinc

The influence of contributing land use on the quality of OGS pool water is evident in Table 1. In general, the concentration of conventional pollutants such as nutrients and suspended solids was similar to many other reported urban stormwater runoff datasets (1). The pool water concentrations of total hydrocarbons, TOC, and soluble and extractable trace metals, however, were much higher. In particular, the average concentration of total hydrocarbons exceeded 10 mg/L in three of the five land uses studied. Analysis of variance indicated that gas station OGS sites had significantly greater pool water hydrocarbon, TOC, zinc, copper, lead, and cadmium levels that any other OGS sites.

The influence of contributing site land use was even more pronounced when sediment quality was analyzed (Table 2). OGS sediments were all heavily enriched with hydrocarbons, TOC, nutrients, and metals. The gas station OGS sites had significantly higher hydrocarbon, TOC, phosphorus, and metals concentrations compared with the other four land uses. Convenience commercial and all-day parking sites generally had higher levels than streets and townhouse parking lots.

## *Effects of Automotive Land Use*

Previous priority pollutant scans of stormwater runoff and pond sediments from primarily residential land uses in the metropolitan Washington area had failed to detect the presence of polycyclic aromatic hydrocarbons (PAHs) (4). Numerous PAHs and other compounds on EPA's priority pollutant list, however, were detected in the automotive-influenced sites of the OGS study (Tables 3 and 4).

**Table 2. Characterization of the Quality of Trapped Sediments in OGS: Effect of Land Use**

| Parameter (mg/kg) | All-Day Parking (N = 8) | Convenience Commercial (N = 6) | Gas Stations (N = 7) | Streets (N = 6) | Townhouse/ Garden Apartments (N = 6) |
|---|---|---|---|---|---|
| TKN | 1,951.0 | 5,528.0 | 3,102.0 | 1,719.0 | 1,760.0 |
| TP | 466.0 | 1,020.0 | 1,056.0 | 365.0 | 266.7 |
| TOC | 37,915.0 | 55,617.0 | 98,071.0 | 33,025.0 | 32,392.0 |
| HC | 7,114.0 | 7,003.0 | 18,155.0 | 3,482.0 | 894.0 |
| Cadmium | 13.2 | 17.1 | 35.6 | 13.6 | 13.5 |
| Chromium | 258.0 | 233.0 | 350.0 | 291.0 | 323.0 |
| Copper | 186.0 | 326.0 | 788.0 | 173.0 | 162.0 |
| Lead | 309.0 | 677.0 | 1,183.0 | 544.0 | 180.0 |
| Zinc | 1,580.0 | 4025.0 | 6,785.0 | 1,800.0 | 878.0 |

TKN = total Kjeldahl nitrogen, TP = total phosphorus, TOC = total organic carbon, HC = total hydrocarbons. All metals are extractable.

A total of 19 priority pollutants were detected in pool water at the gas station OGS sites, compared with seven detected at non-gas-station sites, most of which were metals. Thirteen volatile and semivolatile priority pollutant compounds were detected in pool water at the gas station OGS sites. Semivolatile compounds included phenols, naphthalene, and plasticizers, whereas the volatile compounds included acetone, benzene, toluene, xylene, and ethyl benzene. Most, if not all, of these compounds are linked to gasoline and its derivatives, lubricants, and cleaning agents customarily found at gas stations (5).

An even greater number of priority pollutants, 26, were detected in the trapped sediments of gas station OGS sites. An additional 11 priority pollutants were indicated but were below analytical detection limits. Metals and PAHs dominated the list of confirmed priority pollutants. PAHs found at the highest concentrations in the sediment included 2-methylnapthalene, naphthalene, phenanthrene, fluoranthene, pyrone, and christen. Three of these PAHs have been listed as toxics of concern by the EPA Chesapeake Bay Program (5). Most of these PAHs are strongly associated with gasoline and its byproducts. The gas station OGS sites had the highest sediment metals levels, particularly for cadmium, copper, chromium, lead, and zinc.

Only nine PAHs were recorded at the non-gas-station OGS sites, and in nearly all cases the concentration in the sediments was lower. Interestingly, the only pesticides detected in the sampling were discovered at the more residential non-gas-station sites.

## Discussion

The monitoring study has several interesting implications for urban stormwater runoff and its effective control, which are discussed below.

### *Hydrocarbon Hotspots in the Urban Landscape*

The results suggest that hotspots of possible hydrocarbon and metal loading do exist in the urban landscape, and that these are likely to occur where vehicles are fueled, stored, or serviced. In this study, gas stations and, to a somewhat lesser degree, frequently used parking lots clearly exhibited greater hydrocarbon and metal loading potential than more residential sites. Future monitoring may reveal other potential hotspots such as bus depots, loading bays, highway rest areas, and vehicle maintenance operations.

The traditional management approach for urban runoff quality has been to specify a uniform treatment standard for all impervious areas across the urban landscape (e.g., the first half inch of runoff). Based on the results of this study, a more effective strategy might be to supplement uniform standards with more stringent treatment requirements when a possible hydrocarbon hotspot may be involved.

Only nine PAHs were recorded at the non-gas-station OGS sites, and in nearly all cases the concentration in the sediments was lower. Interestingly, the only pesticides detected in the sampling were discovered at the more residential non-gas-station sites.

### *Possible Link to Estuarine Sediment Contamination*

The bottom sediments of most of the nation's urban estuaries are frequently contaminated with hydrocarbons, PAHs, and metals. The sources of the ubiquitous and pervasive contamination may include air deposition, fuel spills, leaking underground storage tanks, leachate from landfills or industrial sites, industrial discharges, and waste oil dumping, among others. This study suggests

**Table 3. Priority Pollutants Detected in Composite Scans of OGS Sediments**

| Compound (μg/kg) | Gas | Nongas | All Site |
|---|---|---|---|
| **Semivolatile Organics** | | | |
| Napthalene | 9,000 | — | S |
| 2-Methylnapthalene | 24,000 | S | S |
| Acenapthene | 1,800 | — | — |
| Fluorene | 3,200 | — | — |
| Phenathrene | 11,500 | 1,800 | S |
| Fluoranthene | 3,400 | 2,000 | 20,000 |
| Pyrene | 5,800 | 2,300 | 26,000 |
| Butylbenzylpthalate | 3,400 | S | S |
| Chrysene | 2,200 | 1,200 | S |
| bis (2-Ethylhexyl) pthalate | 44,000 | 13,000 | 220,000 |
| Di-n-octyle pthalate | 2,900 | S | S |
| Benzo (b) flouranthene | 1,400 | S | S |
| Indeno (123-cd) pyrene | 1,400 | S | S |
| Benzo (g,h,i) perylene | 1,900 | S | S |
| Di-n-butyl pthalate | S | 1,800 | S |
| **Volatile Organics** | | | |
| Toluene | 6,800 | 2,300 | 7,500 |
| Ethylbenzene | S | 3,100 | — |
| Total xylenes | 6,900 | 13,000 | — |
| Methylene chloride | S | S | — |
| **Pesticides and PCBs** | | | |
| Aldrin | — | 29 | 950 |
| 4,4-DDT | — | 29 | — |
| **Metals** | | | |
| Antimony (mg/kg) | 5.1 | — | — |
| Arsenic | 4.1 | 2.6 | 6.2 |
| Beryllium | 0.3 | 0.5 | 1.6 |
| Cadmium | 6.5 | 0.8 | 7.2 |
| Chromium | 123 | 37 | 91.3 |
| Copper | 126 | 36 | 132 |
| Lead | 493 | 46 | 145 |
| Nickel | 50 | 50 | 95 |
| Silver | — | — | 2 |
| Zinc | 953 | 261 | 1,650 |
| **Cyanide and Phenols** | | | |
| Phenol | 25.6 | 8.0 | 76.2 |
| Cyanide | — | — | — |

S = detected but at concentrations under the detection limit
— = not present

**Table 4. Priority Pollutants Detected in Composite Scans Within the OGS Water Column**

| Compound (μg/kg) | Gas | Nongas | All Site |
|---|---|---|---|
| **Semivolatile Organics** | | | |
| Benzyl alcohol | 10 | — | — |
| 2-Methylphenol | 22 | — | — |
| 3,4-Methylphenol | 32 | — | — |
| 2,4-Dimethylphenol | 16 | — | — |
| Napthalene | 100 | — | — |
| 2-Methylnapthalene | 43 | — | — |
| bis (2-Ethylhexyl) pthalate | 14 | — | — |
| Chrysene | — | — | 12 |
| **Volatile Organics** | | | |
| Acetone | 57 | 13 | 46 |
| 2-Butanone | 16 | — | — |
| Benzene | 18 | — | — |
| Toluene | 140 | 5 | — |
| Ethylbenzene | 41 | — | — |
| Total xylenes | 230 | — | — |
| **Pesticides and PCBs** | — | — | — |
| **Metals** | | | |
| Antimony | — | — | — |
| Arsenic | 1.0 | 1.0 | — |
| Beryllium | — | 1.2 | — |
| Cadmium | — | — | 8 |
| Chromium | 5 | 6.2 | 5 |
| Copper | 72 | 8.3 | 15 |
| Lead | 48 | 3.3 | 5 |
| Nickel | — | — | — |
| Silver | — | — | — |
| Zinc | 373 | 65 | 132 |
| **Cyanide and Phenols** | | | |
| Cyanide | — | — | — |
| Phenol | 86 | 10 | 24 |

that the washoff of leaked fuels and fluids from vehicles may also be a key source of sediment contamination.

The significance of runoff from hydrocarbon hotspots in sediment contamination may be great. For example, 12 out of 13 PAHs present in the sediments of the tidal Anacostia estuary were also present in the trapped sediments of gas station OGS sites. On average, the concentration in OGS sediments was seven times greater than that recorded in the tidal estuary. Of even greater interest is the finding that the relative composition of PAHs in both the river and OGS sediments was quite similar (3). While the possible link between runoff from hydrocarbon hotspots and estuarine sediment contamination remains suggestive rather than conclusive at this point, the subject merits further monitoring and analysis.

### *Opportunities for Pollution Prevention at Hotspots*

Because leakage, spills, and improper handling and disposal of automotive products appear to be the key source of many of the pollutants observed at hydrocarbon hotspots, an effective control strategy involves the use of pollution prevention practices. For small vehicle maintenance operations, these may include techniques to run a dry shop, reduce run-on across work areas, use less toxic cleaning agents, control small spills, store automotive products in enclosures, and, perhaps most importantly, train employees to reduce washoff of automotive products from the site (6).

### *Implications for OGS Cleanout and Disposal*

The original purpose of the study was to establish the characteristics of trapped sediments and pool water within OGS sites to determine the most appropriate and safe disposal method. Based on preliminary data, OGS residuals do not quite meet criteria to be considered hazardous for landfilling (7). Many local landfills, however, may set more stringent criteria and will not accept OGS sediments unless they are fully dewatered. Introduction of OGS residuals into the sanitary system appears also to be prohibited due to utility pretreatment requirements.

Regular cleanout of OGS systems appears to be quite rare. For example, none of the 110 OGS systems surveyed in the field appeared to have been maintained in the last year (2). Given the poor retention characteristics of existing OGS designs, a minimum frequency of quarterly cleanouts would seem warranted to ensure that the trapped residuals are removed before they are resuspended. The cost to cleanout an OGS system and safely dispose of the trapped sediments, however, could exceed $400 per site visit. The need for frequent and costly cleanouts, coupled with the ambiguities regarding the possible toxicity of trapped sediments, raises serious concerns about the effectiveness of the current generation of OGS systems.

### *Outlook for Improvements in OGS Design and Performance*

The study indicates that the current generation of OGS systems does not retain trapped pollutants and therefore must be maintained at an unrealistically high frequency. Clearly, the retention characteristics of OGS must be sharply increased if they are to become a credible urban best management practice.

Several design improvements have the possibility of increasing the retention of pollutants. These include designing the OGS to be fully off-line, so that larger runoff events bypass the OGS and reduce the frequency of sediment resuspension; providing larger treatment volumes; using sorptive media, fabrics, or pads within chambers; and modifying the geometry of each chamber to reduce turbulence in the vicinity of trapped sediments. Until the improved retention of these design modifications is confirmed in the field, however, it may not be advisable to use OGS systems on a widespread basis.

Given the possible importance of hydrocarbon hotspots in the urban landscape and the apparent inadequacy of the current generation of onsite best management practices to control them effectively, it is strongly recommended that an intensive research and demonstration program be started to evaluate alternative small-site runoff treatment technologies.

## Acknowledgments

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## Additional Reading

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# *Design Considerations for Structural Best Management Practices*

**Joseph J. Skupien**
**Somerset County Engineering Department, Somerville, New Jersey**

## Abstract

Upon selection of the appropriate structural best management practice (BMP) to address an urban runoff management need, the design process begins. Successful BMP design does not consist merely of achieving required technical performance levels specified in a government regulation. To meet both the letter and spirit of the regulation and to help encourage the public participation vital to the future of urban runoff management, a responsible BMP designer must also acknowledge and address several other technical and nontechnical considerations.

This paper emphasizes the need for a strong theoretical understanding of standard design models and equations. It also recommends a technique for identifying and evaluating a structural BMP's inherent maintenance, safety, and aesthetic needs that may not be readily apparent when using more conventional design procedures. The paper also identifies the individuals and agencies that will interact with a structural BMP during its design and/or following its construction, and emphasizes the need to include their interests in the BMP design process.

Finally, in recognition of the nascent state of nationwide stormwater management, the paper encourages BMP designers to contribute to the continued development of the field by conducting their designs in an open and objective manner and by continually seeking new and better responses to the many stormwater management challenges we face.

## Introduction

> design \di-zine\ vb 1: to conceive and plan out in the mind; 2: to devise for a specific function or end; 3: to conceive and draw the plans for (Merriam-Webster Dictionary)

This definition succinctly describes both the scope and sequence of activities typically undertaken by the designer of a structural best management practice (BMP). Having identified a stormwater management problem or need that can best be solved through the construction of a structural BMP, the designer then selects the most appropriate type of BMP, conceptualizes its function and operation, and determines the specific characteristics necessary for the BMP to achieve its desired performance. Having completed this, the designer must then transform these characteristics into a physical entity. This is done through the development of detailed construction plans and specifications, which are used to construct the BMP in the field.

Throughout the entire endeavor, the structural BMP designer must, of course, fulfill certain technical responsibilities if the BMP is to comply with the standards and requirements of the community's overall stormwater management program. To do so, the designer must be familiar with these program requirements as well as the technical data, equations, and analytic techniques commonly used to meet them. If stormwater management is to grow beyond its traditional concerns for stormwater quantity to address stormwater quality and nonpoint source (NPS) pollution, however, such technical compliance is not enough. Instead, the BMP designer must also recognize his or her unique responsibilities both to the success of the overall stormwater management program and to the people who will live, work, or travel past the structural BMP they are creating. Only by fulfilling these larger design responsibilities will stormwater management be able to achieve and sustain the public support and participation it needs to effectively address the complex problems that lie ahead of it. A description of each of these design responsibilities is presented below, along with recommendations for fulfilling each.

## The Responsibilities of the BMP Designer

As noted above, the effective BMP designer must fulfill several levels of responsibility. First and foremost, the designer is responsible for complying with the technical requirements and standards of the overall stormwater management program of which the

BMP will be a part. This typically includes achieving the required level and range of peak outflow control necessary to prevent or reduce downstream flooding as well as the detention times and pollutant removal rates necessary for stormwater quality enhancement. Additional technical requirements contained in the stormwater management program may include emergency discharge capacity to insure dam or embankment safety, as well as structural and geotechnical standards to achieve stability and strength. The BMP designer must be familiar with the specific technical requirements of the stormwater management program as well as the theoretical basis for and use of the various hydrologic, hydraulic, structural, and geotechnical analyses typically used to comply with them.

The responsible BMP designer should not only be familiar with the program's technical requirements but also understand the program's overall intent or goals, for the designer must recognize that the program's technical requirements are only the means through which we hope to achieve the program's goals or ends. As such, a structural BMP will contribute more towards those goals if its designer understands, for example, not just what detention time the BMP should have, but why it should have one, why it should be a certain duration, and what will happen if it does not. Such understanding also produces BMP designs that are better able to achieve satisfactory results over a much wider range of real-world conditions than the more limited conditions that are normally analyzed during the design process.

In addition, due to the inherent complexities of stormwater quality and nonpoint source (NPS) pollution, we have not been able in many instances to define the technical requirements of our stormwater management programs as well as we have been able to specify their goals. For example, it is considerably easier to select a goal of 80 percent removal of suspended solids from stormwater runoff than it is to specify the exact technical measures that must be implemented to do so. This disparity between means and ends can be overcome to a great degree by the responsible designer who, aware of the disparity, is willing and able to look behind and beyond the program's somewhat limited technical requirements and produce designs that do a better job of achieving the program's goals.

Another BMP design responsibility is based on the fact that the final product of the designer's efforts will be a real structure that must be constructed and maintained and that will occupy space in a real environment. As such, it is vital that the BMP be both simple and practical in terms of construction, materials, operation, maintenance, and safety. Such characteristics can only be achieved by a designer who is aware of their importance and can define them in physical terms. In addition, such vital characteristics cannot, at times, be achieved by strictly adhering to a stormwater management program's technical standards and may, in fact, require that they even be ignored or broken. Such instances demand the involvement of a responsible designer who will be able to achieve a more informed, effective balance between technical compliance and practicality than is achievable through strict compliance alone.

In the design of any structural BMP, cost must also be an important factor, and the responsible designer not only appreciates this fact but also can accurately and objectively determine both the benefits that a structural BMP provides and the costs of doing so. A true measure of a BMP's cost effectiveness can only be achieved by understanding, quantifying, and comparing both. To do so, the designer has a responsibility to fully understand both the cost of BMP construction, operation, and maintenance and the relative values or benefits to be gained from it. This requires, among other traits, a high degree of objectivity to ensure that the costs and benefits determined by the designer are based on reality and not the interests or desires of his or her client or supervisor, or a government regulator.

Finally, the responsible BMP designer understands the importance of professionalism and will always conduct the design process in an open, honest, and objective manner. In view of the nascent state of stormwater management nationwide, such tenets are particularly vital if we are to close the present gap between what we seek to gain from stormwater management and how we can best achieve it. Such conduct will also enable us to more quickly identify uncertainties, conflicts, and errors in our present understanding of stormwater runoff and NPS pollution and to develop more effective and efficient solutions.

## BMP Design Considerations: Points To Ponder

From the above, it can be seen that the responsible BMP designer must not merely be concerned with the technical requirements of a stormwater management program but, instead, must strive to produce facilities that also achieve and even advance the program's goals and intentions. The structural BMPs that result from such an effort will become assets to the community that they serve and promote the public interest and involvement necessary for overall program success. The BMP must also be practical, safe, aesthetically pleasing, easy to build, and even easier to maintain. Faced with such a formidable list of requirements, the responsible designer must not only bring competent technical ability to the design process but also an informed, open attitude and even a sense of mission or purpose. To help promote such an attitude and more fully prepare the BMP designer for the job ahead, the following points regarding BMP design, construction, and operation are offered. The BMP designer should consider these points before undertaking a design effort.

### *Interested Parties*

To produce a BMP design good enough to earn an "approved" stamp from a stormwater management program regulator (who is presumably interested in ensuring compliance with the program's regulations), a BMP designer must identify with those interests and make sure they are reflected on the construction drawings. To further ensure that the BMP will truly be an asset to the community and will make a positive statement about the value of stormwater management, the BMP designer must consider several interested parties.

#### The Client

Including the client on a list of parties having an interest in a BMP design should not come as a surprise; however, a review of what the client's interests really are just may be. Therefore, the responsible BMP designer will not automatically assume to know the client's interests (however obvious they may appear) but will instead fully discuss them with the client.

The prospect of such a discussion may then lead the designer to ask the following question: What should the client's interests be? Does the client have a misinformed or misguided attitude towards the goals of stormwater management? Is this attitude based on a lack of understanding or information? In such cases, the responsible designer can, through education (and a touch of diplomacy), both expand the client's understanding and improve his or her attitude towards stormwater management, thereby enhancing the designer's own chances of producing a positive BMP design.

#### The Regulator

Similar to the client, the regulator is also an obvious choice for an interested party list. Once again, the following questions may be raised: What are the regulator's interests, and what should they be? Because a regulator's review of a BMP design can sometimes stray from the program's technical standards into more subjective areas (due, in part, to a lack of such standards), it is often helpful to know what interests the regulator has stored up in those areas. Are those interests both in keeping with the goals of the stormwater management program and within the program's (and, therefore, the regulator's) jurisdiction?

For example, a regulator may have a strong interest in promoting proper land use as a means of achieving a program's goals. If regulating land use is beyond the program's scope or authority, however, then such interests have no rightful place in the regulator's review of the BMP design. Should such interests become part of the review, it is the designer's responsibility to point this fact out and redirect the review back to its proper direction. In doing so, all of the diplomatic skills the designer has developed from educating the client will prove invaluable.

Similar to the client, a BMP designer may also encounter a regulator who, through a lack of knowledge or an abundance of wrong information, either misunderstands the program's requirements or lacks the ability to fully ensure their compliance. Once again, the responsible BMP designer can, through education and a competent, comprehensive design, expand the regulator's understanding and ability so that the designer's intentions can be better understood.

#### The Constructor

As noted earlier, one of the key responsibilities of the structural BMP designer is to transform the BMP from concept to reality by preparing detailed plans and specifications of how it should be built. It is then up to the constructor to finish the project by actually building the BMP from these plans and specifications. Therefore, the responsible designer appreciates the efforts of the constructor and does not see his or her own efforts as an independent exercise, but rather as an integral part of a much larger process—a process that requires the constructor to complete.

As such, the responsible BMP designer recognizes and responds to the constructor's interests by producing a well thought-out design that can be constructed as easily and simply as possible. Because this may not always be possible, particularly when faced with complex performance requirements or difficult site conditions, the responsible designer also takes extra care to bring any difficult or unusual aspects of the design to the constructor's attention before the start of construction, even consulting with the constructor during the design phase to mutually devise the best construction technique, material, or sequence.

Under ideal circumstances, the BMP designer will also continue his or her involvement in the project throughout the construction phase and will work with the constructor to correct mistakes, address oversights, and develop revised designs as necessary to overcome problems that may be encountered in the field.

#### The Maintainer

Once construction of the BMP has been completed, the designer's involvement with the process (assuming it lasted through construction) normally ends. However, there are interested parties whose involvement with the BMP is just about to start and whose interests the designer must also consider. These are the maintenance personnel who will be responsible for mowing the grass, removing the sediment, clearing the debris, managing the habitats, and performing the necessary repairs at the BMP for the rest of its serviceable life. Similar to the constructor, the maintainer's actions will be governed by what the designer creates on paper. Because construction has been completed and the designer has moved on to other projects, however, it is considerably more difficult for the maintainer to have deficiencies or oversights in the design corrected.

As such, the designer must understand and address the interests of the maintainer before it is virtually too late. As described in more detail in later sections, this can be accomplished by designing a facility that, optimally, requires a minimal amount of maintenance that can be performed as easily as practicable.

#### The Resident

This interested party may also be the worker, commuter, shopper, student, or local government official who will interact with the structural BMP on a regular basis. This interaction may be physical (through the sense of touch, sight, hearing, or smell) or psychological (as anyone who has worried about children's safety or the value of his or her property will understand).

In any case, these are the people who have, perhaps, the strongest interest in seeing that a positive BMP design is achieved. These are also the people who will soon be asked to participate in the community's nonstructural stormwater management programs by changing some of their aesthetic values and even their lifestyles. Therefore, the person responsible for producing the BMP design must be aware of their interests and incorporate them into the design as well.

### *Operating Conditions*

Just as a wide range of people have an interest in the BMP design, the BMP must operate under a wide range of conditions. Just as the BMP designer may fail to recognize the full range of interests, he or she often fails to consider all of the real-world conditions that the BMP will be subject to by focusing solely on those design conditions necessary for official program approval. This is unfortunate, because the design conditions that received all of the designer's attentions will, in reality, only occur during a small fraction of the BMP's existence. However, its performance during the remainder of its existence, while ignored by the designer, will largely determine the community's opinion of its value.

Therefore, it is important that the BMP designer be aware of all of the weather and other site conditions to which the BMP will be subjected.

#### Design Conditions

These are obviously the designer's first concern and, as noted above, are normally established by the community's stormwater management program. In the case of runoff quantity control, these conditions usually include either a single event or a range of relatively extreme storm events, the runoff from which must be stored and released at a predetermined rate. New Jersey's Stormwater Management Regulations, for example, require that the runoff from a proposed land development site for the 2-, 10-, and 100-year storm events be controlled so that the peak rate of site runoff after development for each storm does not exceed the peak rate that existed before development. The Somerset County, New Jersey, standards are stricter, requiring a peak rate after development that is actually less than existing to account for development-induced changes in runoff volume and overall hydrograph shape as well.

In the case of stormwater quality control, typical design conditions may include the temporary storage and slow release of the runoff from a much smaller, more frequent storm event to promote pollutant removal through sedimentation. For example, the New Jersey Stormwater Management Regulations require the temporary storage of runoff from a 1-year storm event, with release occurring over 18 to 36 hours depending on the character and intensity of the proposed development. The state of Delaware requires extended storage of the first inch of runoff from a proposed site, with release occurring over 24 hours.

Whatever exact design conditions the stormwater management program may specify, it is vital that the structural BMP function properly under them or the goals of the program cannot be met.

#### Extreme Conditions

In addition to the program's design conditions, which have been selected with the goal of runoff quantity and/or quality in mind, the responsible BMP designer must also recognize that more extreme storms may also occur. Therefore, due to the inherent dangers of storing runoff and the exceptionally large quantities of runoff that can be produced by these extreme events, it is vital that the BMP designer also address the goal of safety by ensuring that the BMP will also function properly under such extreme conditions. This will typically include the provision of an emergency spillway or other auxiliary outflow device that will safely convey the extreme event runoff that exceeds the capacity of the BMP's normal outflow structure. It will also include protection of critical portions of any embankment, dam, or discharge points that may be subject to scour or erosion from the high flow velocities generated by the storm event.

### Dry Weather Conditions

While design and even extreme storm conditions can be expected to occur periodically, the most common operating condition at a structural BMP will be dry weather with various seasonal temperatures, winds, humidities, and periods of daylight. While dry weather may be the most prevalent operating condition, it is also the one that is most frequently overlooked by the BMP designer. As a result, how the BMP will look, smell, and even sound during the majority of its operating life is then left to chance. This can be particularly unfortunate for the BMP maintainer and, more critically, the resident, worker, or commuter who will interact most often with the BMP during dry weather conditions. Therefore, the responsible BMP designer will not only address extreme storm events but will also make sure that the BMP performs satisfactorily when it isn't raining at all.

### *Design Methodologies*

Before starting the actual design process, the responsible designer will have an adequate understanding of the selected design methodologies. These methodologies can cover such aspects as rainfall-runoff computations, hydrograph routings, infiltration and ground-water movement, structural design, and geotechnical issues. In doing so, the designer's understanding should include the methodology's theoretical basis, assumptions, limitations, and applicability. In addition, the responsible designer will also have an understanding of both the accuracy needed to perform the design and the accuracy of the method he or she has selected to do it. From this, the responsible designer will neither waste time producing unneeded accuracy nor attempt to achieve a level of accuracy beyond the limits of the method. Finally, the responsible designer will understand the sensitivity of each of the method's input variables and will appropriately allocate his or her time and resources in developing each one.

### *Facility Type*

The final point for the BMP designer to ponder before beginning the actual design process is the type of structural BMP to be used. Presently, a wide range of facilities are available for use, ranging from relatively simple vegetated filter strips and swales to large ponds and constructed wetlands. Selection of the appropriate BMP depends on several factors, including program requirements, BMP location, site conditions, maintenance needs, safety, cost, and performance characteristics.

Similar to BMP operating conditions, the BMP designer may often consider only a few of these factors, most notably program requirements (keep the regulator happy) and cost (keep the client happy, too), in making his or her selection. The responsible designer, however, will recognize the performance, needs, uncertainties, and risks inherent in each type of BMP and will then select (or help influence the selection of) the most appropriate type of BMP for the site. This process typically begins with the identification of the fundamental characteristics of each type of BMP, along with the project's physical, economic, social, and regulatory constraints. The process then becomes one of comparison and analysis, with the best match found by eliminating the worst.

For example, a site with porous soils, low ground-water table, and close proximity to residences may not be best suited for a wet pond or constructed wetland, while the active recreational needs of the residents may benefit from a dry, extended detention basin that can also serve as an athletic field. Although perfect matches rarely occur, comparisons and analyses such as this will help reduce the number of potential BMPs, improve the thoroughness and objectivity of the overall selection process, and ideally produce the optimal facility type. This process can even help identify inherent weaknesses in or problems with the selected type, which will enable the responsible BMP designer to devote additional time and effort towards correcting them during the design phase.

To undertake such a selection process obviously requires a designer who understands the fundamental characteristics and needs of each BMP and who can objectively assess all of the pertinent site constraints. Such a designer must also be willing and able to confront the differing opinions of other, less objective or informed parties (including the regulator and client) to ensure that the best BMP is selected. As noted throughout this paper, achieving an optimal BMP design is a complex and demanding process that must incorporate numerous interests and requirements. Starting the process with the wrong facility type, however, transforms a complex and demanding process into an impossible one.

## BMP Design Considerations: A Checklist

Having completed the BMP selection process with honor, idealism, and design contract still intact, and armed with both the necessary technical and regulatory knowledge and economic and social sensitivity, the responsible BMP designer is ready to begin the actual design process. Presented below is a checklist of six key design considerations to help guide this effort. Ideally, these six items have or will become an integral part of the designer's thought process and will automatically be included in each design effort. These items can also serve as guidelines for those responsible for the review and approval of specific BMP designs as well as goals for those developing new stormwater management programs.

### Safety

For several reasons, the safety of the structural BMP must be the primary concern of the designer. Due to its "structural" nature and, in many instances, the fact that it will impound water either permanently or temporarily, the structural BMP will inherently pose some degree of safety threat.

Those at risk include people living, working, or traveling downstream of the BMP whose safety and/or property will be jeopardized if the BMP were to fail and release stored runoff. Because this is a risk that has been created solely by the BMP, the designer must ensure that the probability of such a failure is acceptably small.

Also at risk at a structural BMP are maintenance personnel, inspectors, mosquito control personnel, and equipment operators, who must work in and around the facility. Typical hazards include deep water, excessively steep slopes, slippery or unstable footing, limited or unsafe access, and threats posed by insects and animals. As noted above, the responsible BMP designer understands the importance of facilitating BMP maintenance. Providing a safe working environment for the BMP maintainer is one important way to do it.

Finally, those living, working, attending school, or playing in the vicinity of a structural BMP may also be at risk, particularly if the BMP serves both as a stormwater management and recreational facility. Once again, such things as standing water, steep slopes, unstable footings, and insect and animal bites must be addressed by the designer to avoid creating a facility that is a detriment to the community it is intended to serve. Failure to do so will only alienate those members of the community who will be asked to play a vital role in future stormwater management efforts.

### Performance

Having made a strong commitment to safety, the BMP designer must then consider facility performance. This normally includes achieving the necessary stormwater detention times, flow velocities, settling rates, peak flow attenuation, and/or ground-water recharge for the range of storm events to be managed. Again with a commitment to safety, the designer must also ensure that the BMP performs adequately under emergency conditions, most notably when the peak rate and/or volume of runoff flowing into the basin exceeds the discharge capacity of the BMP's principal outlet. This will require the inclusion of emergency or auxiliary outlets in the BMP to safely convey this excessive inflow through the BMP without jeopardizing its structural integrity.

In most instances, the performance standards that the BMP design must meet will be specified in the stormwater management program's regulations. Experience has shown, however, that these performance standards may, at times, be vague, contradictory, or even impossible to meet. For example, many BMP designers have been confronted with a requirement to reduce both the peak rate and total runoff volume from a developed (or developing) watershed to predeveloped levels. This has often lead to much head scratching, for the solution normally requires the use of an infiltration or recharge basin which, due to site constraints, may either be impractical or impossible. Faced with such circumstances, the responsible designer looks beyond the written regulations and investigates their origins and true intent with regulatory personnel. Direct inclusion of these individuals in the design process will also help ensure more positive overall results.

### Constructability

Up until now, the designer's efforts to achieve adequate BMP safety and performance levels have been achieved only on paper or computer disk. Because the ultimate goal of the design process is to actually create a BMP, the BMP designer must also give careful consideration to how it is to be constructed. Achieving exceptional safety and performance characteristics in a BMP that cannot actually be built solves nothing and wastes much. Achieving required levels of safety and performance in a BMP that can be reconstructed with relative ease using readily available materials, equipment, and skills is commendable and not only solves a specific stormwater management problem, but also helps to advance the community's overall program. "Constructability" can be defined as a measure of the effort required to construct a structural BMP. A BMP that is highly "constructable" utilizes materials that are readily available, relatively inexpensive, and do not require special shipping or handling measures. They will be both durable and easily modified in the field to meet specific site conditions. Similarly, the construction techniques and equipment required to construct the BMP will also be relative simple, straightforward, and familiar to the people who will be performing and operating them.

It is important to note that the above description is not intended to discourage the use of new or innovative materials or construction techniques, nor to inhibit creativity in the BMP design process. In fact, innovation in design and construction is vital to the future growth of stormwater management. Instead, the above description of "constructability" is intended to remind designers that they must consider the construction aspects of the BMP in the design process and strike a balance between performance and safety requirements, constructability, and innovation for each design they undertake.

### *Maintenance*

The same reminder stated above for constructability must also be said for BMP maintenance. Similar to construction, the degree of effort and expense required to adequately maintain a structural BMP will help determine the overall success of its design. A BMP with manageable maintenance needs can be expected to remain in reasonably good condition and has a stronger chance of becoming an asset to the surrounding community. On the other hand, a BMP with excessive maintenance needs is likely to be neglected and will quickly become a community liability. As such, BMP maintenance can directly effect the overall success of the community's stormwater management program.

The BMP designer can help determine a BMP's maintenance needs by considering several aspects of that maintenance in the design process. First, the BMP design should include the use of durable materials that are able to withstand the many and varied physical conditions that the BMP will experience over its lifetime. Secondly, suitable access to key BMP components and areas is vital if required maintenance levels are to be achieved. This will include provisions for walkways, staging and disposal areas, access hatches and gates, and safe, stable working areas. The frequency of maintenance has a large impact on both maintenance cost and quality, and it is the designer's responsibility to achieve an appropriate level. Finally, the BMP designer should always strive to minimize the overall amount of maintenance at the BMP and to make that amount as easy as practicable to perform.

### *Cost*

Inclusion of a BMP's cost in a list of design considerations is not surprising. Once again, however, a review of the full costs associated with a structural BMP may yield a few surprises that may increase designers' understanding and encourage them to give BMP costs the full consideration they deserve.

The most obvious BMP cost is its construction. This can be estimated with reasonable accuracy and is the cost most directly borne by the designer's client. As such, designers most often focus on this cost during the design process to the exclusion of all others.

What other costs may be overlooked? One may be the designer's own fee, which is part of the overall BMP cost but which has probably been excluded from consideration because it has already been determined. The designer's fee, however, has a direct impact on the BMP design because it determines the effort and resources the designer uses to produce it. The level of effort expended during the BMP design can have a similarly direct effect on the effort and cost of both construction and maintenance. The greater cost of a more thorough BMP design can ultimately result in cost savings to the client during subsequent project stages. Therefore, while this is not a signal to BMP designers to raise their fees, it is meant to remind designers that their fee is part of the overall BMP cost and that it is their responsibility to determine what level of design effort and cost represents the best investment for both the client and the community.

Another portion of total BMP cost that is frequently overlooked is the cost associated with its maintenance. While this cost on an annual basis is usually a small percentage of the construction and even the design cost, it must be remembered that, unlike construction or design, maintenance costs are recurring and must be paid throughout the life of the BMP. Therefore, while a maintenance cost savings may appear to be insignificant on a per-operation basis and not worth the extra investment in design or construction required to achieve it, its value may be viewed quite differently when multiplied by the numerous times it will be realized. As such, an added investment in design to produce a trash rack that will require less frequent cleaning or an added investment during construction to reduce the frequency of repairs may quickly yield a positive return in the form of reduced maintenance costs. Similar conclusions can be reached for many other design and construction efforts, such as providing better access, using more durable materials, and selecting a BMP that best suits site conditions.

### *Community Acceptance*

The final recommended design consideration once again involves those people who may have the greatest interest in the structural BMP. Not coincidentally, these are the same people who will have the greatest role in the various nonstructural programs intended to augment and even replace structural BMPs in the future. To protect those interests and encourage assumption of that role, it is up to the designer to help achieve a structural BMP that will be reviewed as a community asset rather than a liability.

As discussed above, this can be achieved by considering the aesthetic value of the BMP, preventing the creation of nuisances and safety threats, as well as achieving required performance levels. Through all three, stormwater management gains the understanding and credibility it requires within the community.

## Suggested Design Review Techniques

Throughout this paper, the BMP designer has been encouraged to consider a wide range of interests, operating conditions, costs, and other responsibilities throughout the design process. Presented below are two recommended techniques to help accomplish it. They can either be used as review techniques following completion of a preliminary BMP design or, ideally, be incorporated into the overall design process and used continually throughout it.

### *Spend a Mental Year With the BMP*

To use this technique, the BMP designer simply imagines conditions at the constructed BMP throughout a full year. This should not only include rainy and sunny weather, but also light rain showers (with little or no runoff), light and heavy snowfalls, and frozen ground conditions. Other site conditions may include late autumn, when trees have lost their leaves and the BMP has found them, and hot, dry weather or even drought, when the turf or other vegetation is stressed or even killed. Finally, the designer may wish to imagine what the BMP will be like at night.

As these conditions are visualized, the designer should also imagine how those conditions may effect not only the operation of the BMP itself but also the people that will interact with it. Can blowing snow completely fill the BMP, leading the unsuspecting pedestrian to think that the grade is level? Will the outlet structure's trash rack be particularly prone to clogging by fallen leaves, particularly from the trees the designer just specified for the BMP's bottom?

What about the ice that will form on the surface of a pond or constructed wetland? Can someone fall through? Could that someone be a child taking a shortcut home? How will people be warned not to? How will they be rescued if they do anyway? What about night conditions? Will the constructed wetland next to the office parking lot that is so attractive during summer lunch hours become a safety hazard to workers walking to their cars in the winter darkness? Or will that same summer sun and a lack of rainfall produce some of the wonderful aromas of anaerobic decomposition?

At first, it may be exasperating to realize that the possible site conditions and circumstances can be as numerous and varied as the number of possible BMP uses. But then again, that is the point of the exercise. It is intended to help the designer consider and design for all conditions at the BMP, not just the 1- or 100-year storm event required by the regulations. In doing so, the BMP designer will not only meet the letter of the regulations but will raise the spirit of the entire stormwater management program.

### *Who, What, When, Where, and How?*

The second recommended review technique a BMP designer may employ is to simply focus on one or more characteristics or functions of the BMP and then ask (and attempt to answer) the above questions. For example, let's consider BMP maintenance and then ask:

- Who will perform it? Does the BMP design require specialists, or will someone with general maintenance equipment and training be able to do the job?
- What needs to be maintained? Preparing a list of all the BMP components included in a design that will need attention sooner or later may prompt a revised design with a shorter list.
- When will maintenance need to be performed? Once a day? A week? A year? Remember, the recurring costs of BMP maintenance can be substantial. In addition, can maintenance only be performed during dry weather? If so, what happens during 2 or 3 weeks of wet, rainy weather? What happens when repairs need to be made or debris removed during a major storm event? In terms of effort and possible consequences, it is easier for the designer to find answers to these questions now than for maintenance or emergency personnel to scramble for them later.
- Where will maintenance need to be performed? Will the maintainer be able to get there? Once there, will he or she have a firm, safe place to stand and work? In addition, where will such material as sediment, debris, and trash removed from the BMP be disposed of? Before answering that question, do you know what is in it? Are there toxics or hazardous materials in the sediment or debris? If so, is the place you originally intended to use still suitable? Once again, it is easier to address these questions now then when the dump truck is loaded and the engine's running.
- How will maintenance be performed? The simple instruction to remove the sediment or harvest the vegetation can become rather complicated if no provisions have been made to allow equipment to get to the bottom or even into the site. "Mowing the grass" can become "risking your limbs" on long, steep slopes. How will you explain to your client why the BMP in which he or she has invested has become a liability to themselves and their community?

Similar exercises can be performed with constructors, inspectors, and residents as the object of inquiry. For example, where will the nearest residence be? How will the constructor build the emergency spillway? When will the inspector need to visit to check for mosquitos?

Similar to the "mental year" review technique, the questions raised in this technique are intended to make the designer more aware of all the possible impacts the BMP may have and, further, to encourage the designer to address those impacts now, during the design phase, rather than leave them for others to cope with later. Even if the designer cannot completely answer all of the questions, he or she will be able to advise the others of any unavoidable needs or problems that will be inherent in the BMP and allow them to adequately prepare.

## Summary

Stormwater management must still be considered a relatively new endeavor, particularly on a nationwide basis. Despite its nascent state, it has been charged with the responsibility of addressing some very complex environmental problems. For stormwater management to grow to the level demanded by this charge, the designers of structural BMPs must be willing to assume a degree of responsibility for that growth. BMP designers can fulfill that responsibility by producing BMP designs that do not merely meet official regulations and standards, but help inspire new, better, and more comprehensive ones. BMP designers must also incorporate a wide range of interests into the BMP design, including those held by stormwater program regulators, BMP constructors and maintainers, and all those members of the community who will interact with the BMP over its lifetime. During the design process, BMP designers must not only consider the BMP's performance but also its cost, durability, ease of construction, and maintenance needs. Finally, BMP designers must always recognize the BMP's impacts both on the community around it and on the stormwater management program with which the community has entrusted them.

# *Targeting and Selection Methodology for Urban Best Management Practices*


**Peter Mangarella, Eric Strecker, and Gail Boyd**
**Woodward-Clyde Consultants,**
**Oakland, California, and Portland, Oregon**



## Abstract

Selecting best management practices (BMPs) to implement as part of a stormwater management plan is quite difficult and controversial because of a variety of technical, regulatory, institutional, and financial factors and constraints. Specifically, the nature and sources of stormwater-borne pollutants and the water quality and ecological problems these pollutants cause are not well understood. The cost, effectiveness, and applicability of many BMPs are also not well understood, although several BMP manuals summarize existing information. The federal National Pollutant Discharge Elimination System (NPDES) stormwater regulations provide flexibility in selecting BMPs to control urban pollutants. EPA gives only general guidance on the types of BMP programs that are desirable and does not require the implementation of specific BMPs. Several other factors contribute to difficulties in selecting and implementing BMPs. In many cases, institutional jurisdictions do not correspond to watershed boundaries, and water management institutions' roles and responsibilities are fragmented for effectively dealing with the myriad nonpoint sources of pollution associated with stormwater drainage systems. Finally, the availability of funds, which are currently very limited, significantly determines BMP implementation.

This paper provides guidance on the selection of BMPs given this current environment and based on experience in developing stormwater management plans for areawide programs, individual municipalities, industries, developments, and government facilities. The paper describes the current tools available for BMP selection, a 10-step "model" selection process, and case studies for a large areawide municipal program and for an industrial facility.


## Introduction

In October 1990, the U.S. Environmental Protection Agency (EPA) issued regulations requiring certain municipalities and industries to select and implement best management practices (BMPs) to control pollution associated with stormwater runoff and dry weather discharges into storm drain systems. Such BMPs would be selected and described in stormwater management plans and implemented in compliance with an NPDES permit. The specific regulatory language in Section 402(p) of the Clean Water Act is "Permits for discharges from municipal storm sewers shall require controls to reduce the discharge of pollutants to the maximum extent practicable . . . ." The maximum extent practicable (MEP) standard has a legal definition; however, considerable uncertainty exists in the regulated community about what constitutes technical compliance with the MEP standard.

Other existing and proposed regulations require BMP selection. Section 303 of the Clean Water Act requires that delegated states and EPA establish total maximum daily loads (TMDLs) for designated "water quality limited" water bodies. The TMDL process considers both point and nonpoint sources. For nonpoint sources, water quality management plans must be developed to meet load allocations for urban and other land uses. The 1990 Coastal Zone Act Reauthorization Amendments (CZARA) require the development of state nonpoint source control plans for the coastal zone using BMP guidance recently released by EPA and the National Oceanic and Atmospheric Administration (NOAA).

Finally, watershed planning is gaining favor as a way of meeting water quality goals for the nation's waters. The watershed planning approach requires examination of all land uses and activities in a watershed and development of BMPs to protect water quality. EPA is considering the watershed approach for the phase II portion of the NPDES program.

This paper describes our experience in selecting BMPs for clients complying with the NPDES stormwater regulations; the process would also be applicable to TMDL, coastal zone, and watershed planning. We discuss types of BMPs and sources of information on BMPs available for developing management plans. Based on our experience, we also describe the attributes of a good selection process and describe the steps involved in a "model" selection process. Because of numerous site-specific conditions that enter into any selection process, the actual process chosen must be adapted to each situation. To illustrate how such a process might be adapted to different circumstances, we describe two case studies, one for a large areawide municipal program and one for multiple federal facilities regulated as industrial dischargers.

## Best Management Practices

Although BMPs may be organized in many ways, it is useful in the selection process to distinguish controls based on how they function. BMPs based on function are often considered as source controls, treatment controls, and hydraulic controls.

- *Source controls* are intended to prevent pollution in the first place (i.e., pollution prevention) or to intercept the pollutants before they enter the storm drainage system. Preventing pollution in the first place often involves behavior modification, which requires public information and education, an important source control BMP. Street sweeping and catch basin cleaning are examples of source controls that intercept pollutants before stormwater carries them into receiving waters.

- *Treatment-based controls* are controls that remove pollutants from stormwater, usually through some structural means such as a detention basin or grassy swale.

- *Hydraulic controls* are structural controls that reduce the volume of runoff (or otherwise alter the runoff hydrograph) or divert flows away from source areas. Examples of hydraulic controls are infiltration systems.

In general, the effectiveness of these types of controls are not well understood. The effectiveness of treatment and hydraulic controls generally can be measured through monitoring, and there is an increasing body of literature regarding the effectiveness of treatment and hydraulic controls under limited conditions. Federal, state, and local agencies have developed numerous BMP guidance manuals to help identify, select, and design BMPs. The following is a partial list of manuals, starting with design manuals that contain detailed control selection and design information.

- U.S. EPA. 1993. Handbook: Urban runoff pollution prevention and control planning. EPA/625/R-93/004.

- City of Austin Environmental Resource Management Division. 1991. Environmental criteria manual. Environmental and Conservation Services Department (February 19).

- Metropolitan Washington Council of Governments (MWCOG). 1987. Controlling urban runoff: A practical manual for planning and designing urban BMPs. Prepared for Washington Metropolitan Water Resources Board (July).

- State of Florida Department of Environmental Regulation. 1988. The Florida development manual: A guide to sound land and water management (June).

- State of Washington Department of Ecology. 1992. Stormwater management manual for the Puget Sound Basin (the technical manual) (February).

- Urban Drainage and Flood Control District. 1992. Urban storm drainage criteria manual. Denver, CO (September).

- Metropolitan Washington Council of Governments (MWCOG). 1992. Design of stormwater wetland systems. Prepared for the Nonpoint Source Subcommittee of the Regional Water Committee (October).

The following documents primarily discuss control effectiveness and do not contain control selection and design information:

- City of Austin Environmental Resource Management Division. 1990. Removal efficiencies of stormwater control structures. Environmental and Conservation Services Department (May).

- Metropolitan Washington Council of Governments (MWCOG). 1992. A current assessment of urban best management practices. Prepared for the U.S. Environmental Protection Agency (March).

- U.S. EPA. 1990. Urban targeting and BMP selection: An information and guidance manual for state nonpoint source program staff engineers and managers. Region 5, Water Division, Chicago, IL 60604 (November).

- Metropolitan Washington Council of Governments (MWCOG). 1992. Analysis of urban BMP performance and longevity.

- U.S. EPA. 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA/840/B-92/002. Washington, DC (January). (Includes costs.)

- California State Stormwater Task Force. 1993. California BMP handbooks for municipal, construction, and industrial/commercial (April).

Finally, the following document addresses BMP costs:

- Southeastern Wisconsin Regional Planning Commission. 1991. Costs of urban nonpoint source water pollution control measures. June.

These manuals describe BMP function, requisite site conditions, existing performance information, and cost ranges. In general, these manuals are well written and provide a good starting point for developing an understanding of the advantages and disadvantages of many treatment-based controls. For some BMPs, there is limited information on effectiveness and cost; for these, pilot testing may be helpful under site-specific conditions.

Treatment-based controls are especially applicable in construction and new developments, where structural measures may be incorporated into the construction process and site design. The cost of constructing and maintaining treatment-based controls is a major concern to municipal and industrial dischargers.

In contrast to treatment-based controls, source control effectiveness in terms of water quality improvement cannot easily be measured, if at all. For example, the effect of a public education program on improving water quality cannot be determined, although some public education activities obviously are more effective than others. The effectiveness of street sweeping and catch basin cleaning on water quality requires careful and expensive paired catchment types of studies. Source controls are generally considered the most cost-effective long-term solution because they address the cause of the problem; thus, we see many programs focusing on source control measures.

## Attributes of a Good Selection Process

The following sections describe some attributes of a good selection process.

### *Keep It Simple and Straightforward*

BMP selection for nonpoint source controls is in its infancy compared with point source controls, for which treatment technologies and associated costs are well understood. Instead of traditional cost benefit analysis, nonpoint source BMP selection is more of an art and requires experience, sound judgement, and common sense. Though the process of selection may involve several steps, the process itself must be easily understandable and accepted by the various interest groups involved, including public agency staff and decision-makers, environmental groups, and regulatory personnel.

### *Document the Process*

It is essential to carefully document the process by which BMPs were selected and the various assumptions and considerations made during the selection process. In other words, the process, even though it may be subjective in part, should not be “arbitrary and capricious.” The selection process must be clear to reviewers in evaluating the adequacy of the process in meeting the intent of the regulations. Also if the process is clear, it can be improved or modified in the future as more information becomes available or policies change.

### *Be Comprehensive*

The federal regulations require a comprehensive approach such that a broad range of controls are evaluated for various land uses and activities. The selection process must evaluate a comprehensive list of BMPs to address pollutants of concern and their sources.

### *Plan for Implementation*

Human nature being what it is, effectively implementing many BMPs at once is difficult. The solution to this dilemma is to minimize the number of BMPs chosen, prioritize or phase their implementation, and/or group related BMPs into a few categories, sometimes called program elements.

### *Involve Affected Parties in the Process*

A second element of human nature is adverseness to implementing someone else’s plan. Therefore, BMPs are selected ideally by those who have to implement them (with guidance, of course). A second alternative is that the process heavily involves those who will implement the BMPs in a review and approval role. If neither of these approaches are followed, the plan is not likely to be well implemented.

Indeed, involvement of the affected parties in the selection process is probably more important to the success of the program than the exact nature of the process itself. Through this process, the parties become educated regarding problems, possible solutions, and the need for teamwork in implementing solutions.

## Model of a Good Selection Process

There is no one correct selection process as the process must be tailored to local institutional, political, and regulatory conditions. Figure 1 is a schematic showing six steps in a BMP evaluation, selection, and planning process that are generally applicable. The following is a somewhat expanded discussion of BMP selection steps appropriate for most areawide municipal programs.

### *Step 1: Establish Program Goals and Objectives*

The clients must agree on a compliance strategy from which will stem goals and objectives for the program. The strategy should address such issues as organization and administration, decision-making, coordination with other interest groups, and degree of proactiveness.

### *Step 2: Identify Receiving Waters, Problems, Pollutants, and Resources*

The ultimate intent of the regulations is to protect and improve the water quality and ecology of receiving waters, and this goal should drive the BMP selection proc-

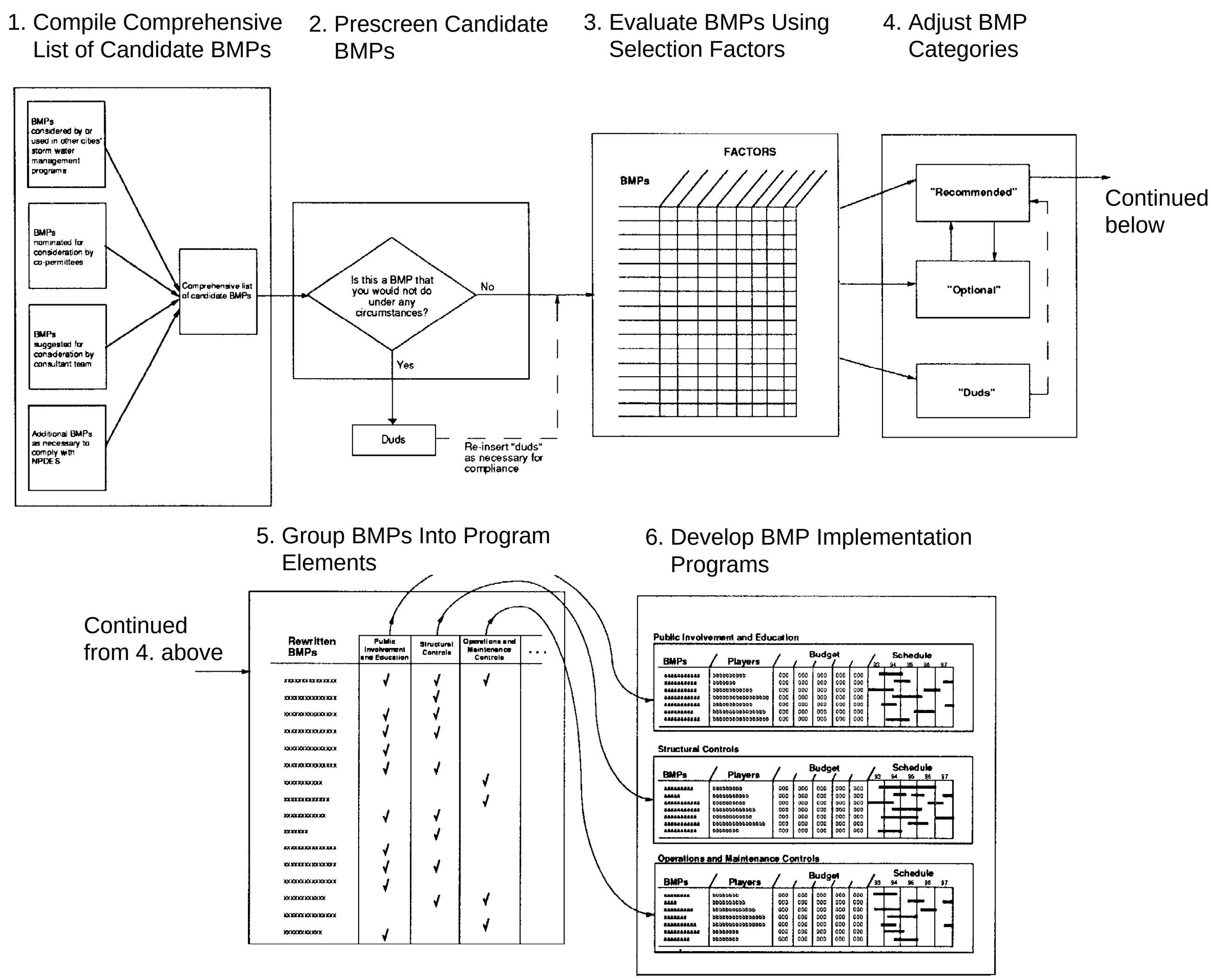


**Figure 1. BMP evaluation, selection, and planning process.**

ess to the extent possible. Ideally this step identifies water resources of particular value that are especially critical to protect, as well as impaired water bodies (e.g., 304(L) segments) that are currently not meeting water quality objectives appropriate for the beneficial uses. Where data are available, pollutants to be controlled should be identified. Without this step, much work and resources may be focused on activities that do not necessarily translate into an improved aquatic environment. Many programs find that a nontechnical one- or two-page “fact sheet” on receiving water problems, pollutants, sources, and management implications helps to develop support from taxpayers and decision-makers.

### *Step 3: Identify Sources and Pathways*

Given the problems, the next step is to try to identify the important point and nonpoint sources of pollutants that are causing the problems. This is an essential step, because control of nonpoint sources only makes sense to the extent that it is a major source of the problem pollutant. For nonpoint sources, try to describe the pathway from source to receiving water, because this helps identify the BMPs that can most effectively intercept the pollutant along the pathway. For example, dumping waste oil into catchbasins can be mitigated by labeling storm drain inlets and/or requiring a monetary deposit at the point of purchase. It should also be pointed out that some sources may be quite difficult to control (e.g., natural erosion).

### *Step 4: Prioritize Sources (Areas) for Control*

Targeting sources for BMP application is the next step. Focusing resources on selected areas is important, otherwise resources tend to be spread too thin to be effective. This is particularly important in municipal programs, where some early “successes” encourage the participation and financial support of local citizens.

A systematic targeting scheme using a ranking process based on stream size, beneficial uses, pollutant loads, and ease of implementation of the BMP is provided in U.S. EPA (1) and U.S. EPA (2). Use of these manuals might be appropriate after an areawide plan is developed; for example, a BMP might be to begin basin planning for selected basins within a city. The targeting manual (1) could be used to identify the basin and subbasins for BMP selection.

### *Step 5: Identify and Evaluate Existing BMPs*

Compile a list of existing BMPs that are currently being conducted and organize them according the sources identified in Step 5. Identifying existing measures is often very difficult. Some municipalities do not know their system very well and are organized into departments in such a way that no one department is aware of what stormwater measures are currently being implemented. Carefully crafted questionnaires work quite well at developing information on existing practices that affect stormwater quality. Evaluate the effectiveness of these measures and improve or discontinue as appropriate.

This step also involves identifying existing environmental programs that are conducting activities that relate to stormwater pollution control and with whom cooperation should be sought. Examples include pretreatment programs, HAZMAT programs, solid waste control and recycling programs, and public information programs.

### *Step 6: Compile Candidate BMPs*

Compile a comprehensive list of candidate BMPs that may be appropriate. This list should contain both source- and treatment-based controls and include such things as regulatory authority. Attach attributes to each BMP, including (if available) pollutant type controlled, cost, and effectiveness. (Recall that such information is generally not available for source controls.) Note dependencies or synergistic relationships between BMPs. For example, some BMPs may be more effective if or may require that another BMP is implemented before or at the same time.

### *Step 7: Develop Selection Criteria*

In addition to the obvious criteria that the BMP address the problems and sources identified in Steps 2 and 5, developing a list of additional criteria that can be used to assist in the selection process is helpful. Such criteria include regulatory requirement compliance, effectiveness, reliability and sustainability, implementation and continuing costs, equitability, public and agency acceptability, risk and liability, environmental implications, and synergy with existing or other BMPs.

### *Step 8: Apply Criteria for Selection of Baseline Measures*

Selection criteria may be applied in numerous ways. For example, applying different criteria in multiple screening "passes" is a common procedure. BMPs may be required to meet "critical criteria" such as obtain co-permittee acceptance, address the problem pollutants and sources, and meet regulatory requirements. Then, in a second "pass," those BMPs that met the critical criteria are further evaluated by applying additional criteria that would help to select preferred BMPs. Such criteria could include effectiveness, cost, and reliability. Often the second pass allows the municipality to help determine what is financially feasible. In the second pass, qualitative (e.g., high, medium, low) or simple quantitative (e.g., 1, 2, 3) scoring might be used to help rank preferred BMPs. Unequal weighting can be assigned to each criteria as appropriate.

BMP selection should also anticipate the evolution of the program. For example, we often recommend that a set of "baseline" BMPs be selected that fully exploits the existing control measures and focuses on additional source control. The selection process can then be used to select the baseline measures and also candidates for a reserve list of BMPs that could be implemented at a later time based on experience with the baseline BMPs.

### *Step 9: Implement Baseline Measures*

Implement the baseline measures with appropriate phasing to allow for planning, pilot testing, etc., prior to full scale implementation. For each BMP, develop measures of effectiveness. As described above, baseline measures tend to be source controls.

### *Step 10: Monitor Effectiveness and Reevaluate BMPs*

Monitor the effectiveness of each BMP and, based on monitoring, annually reevaluate each BMP. As appropriate, delete or select additional BMPs. Annual evaluation should also include any new information obtained through monitoring receiving waters and/or source identification studies.

## Case Study 1: Areawide Municipal Program

The following describes a case study of the BMP selection process that multiple agencies who were part of an areawide stormwater program conducted.

County X is 200 square miles in area and contains 20 co-permittees consisting of municipalities, the county, and a special district. The county population is 1 million people. The municipalities cover a wide range of sizes and land uses, from one city of 100,000 population with major industrial facilities down to small residential cities of 10,000 population. At the behest of the state environmental agency, the co-permittees elected to form a countywide stormwater pollution control program to comply with the federal NPDES stormwater regulations. During the Part I application, the co-permittees compiled a list of existing BMPs.

The co-permittees were very concerned that their management plans reflected local conditions and resources and insisted that they each conduct the BMP selection process themselves. We refer to this approach as the "bottom up" approach, in contrast to the "top down" approach in which BMP selection is conducted by the program and then distributed to the co-permittees for their review and approval. Woodward-Clyde Consultants (WCC) acted as facilitators by designing a process for BMP selection that included development of guidance documents, workshops for all co-permittees, and meetings with individual cities. Program representatives and WCC met with the individual jurisdictions three times throughout the process to provide assistance or clarification. The process from start to finish took about 9 months.

The following guidance documents were developed:

1. Description of Management Plan Development Process
2. Selecting the "Right People" To Participate in the Process
3. Source Identification
4. BMPs for Industrial Facilities
5. BMPs for Agency Activities
6. Transportation BMPs
7. Illicit Discharge Elimination BMPs
8. Commercial Area BMPs
9. Construction and New Development BMPs
10. Public Education and Industrial Outreach BMPs
11. How To Complete Your Stormwater Management Plan

The guidance documents included tables that each co-permittee was asked to complete based on guidance provided. The tables formed the basis of each entity's plan. A key element in the process was a problem and source identification step (Guidance Document 3), in which each entity identified receiving water problems, water resources of special interest, and pollutant sources. Based on this problem identification, cities selected BMPs to address source areas in their jurisdictions.

Guidance Documents 4 through 9 described a menu of individual BMPs from which the cities could select. In addition, WCC recommended a basic list of BMPs applicable for most jurisdictions. The co-permittees chose to participate in a countywide public education program involving various BMPs described in Guidance Document 10. Guidance Document 11 explained how to "put it all together."

An example of a BMP description is given in Table 1. The information provided consisted of a BMP name and identifier, description, steps for implementation, methods to assess effectiveness, and remarks. For those BMPs selected, co-permittees were asked to show when tasks would be completed, and the budget for each BMP over the 5-year permit period.

The BMP information was intended for guidance only, and some jurisdictions revised or created new BMPs that better addressed their circumstances. Some jurisdictions showed real creativity and enthusiasm in developing BMPs. This participatory process results in a much more implementable, practical, and effective stormwater management plan.

## Case Study 2: Industrial Facility

Selection of BMPs for industrial facilities is more site specific and tends to be guided by the types of activities being conducted at the facility. The process of BMP selection then involves identifying industrial activities that could potentially generate sources, identifying the types of pollutant releases associated with

**Table 1. Best Management Practices for Agency Activities and Facilities**

| Number | AA-11 |
|---|---|
| Best Management Practice | Reduce agency use of herbicides and pesticides. |
| Description | Reduce the use of herbicides and pesticides on city streets, landscaping in parks, flood control channels, municipal golf courses, etc. |
| Steps for Implementation | 1) Assess current herbicide and pesticides uses (e.g., types, amounts, areas used).<br>2) Research areas where less toxic substances could be substituted or usage could be eliminated altogether (e.g., use of mosquitofish rather than pesticides).<br>3) Develop implementation programs for various areas. |
| Methods To Assess Effectiveness | Compare amounts and types of herbicides and pesticides currently used with amounts and types used after implementation of the program(s) to demonstrate overall reduction and/or transition to less toxic substances. |
| Remarks | Coordinate with public education and industrial outreach component for public education in the area of residential herbicide and pesticide use. |

each source, identifying optional BMPs that would prevent or eliminate that source, and selecting the preferred option. The following describes a pared-down process of BMP selection that we have used on several industrial projects.

### *Step 1: Identify Drainage System and Receiving Water*

Define the drainage system and receiving waters, including water quality and other concerns in receiving waters. Ensure plant personnel (particularly nonenvironmental personnel) understand the receiving water and regulatory issues when they are involved in the BMP selection process.

### *Step 2: Identify Industrial Activities and Associated Pollutant Sources*

Discuss what industrial activities are conducted at the facility and how these activities might lead to discharges into storm drain systems. This can best be accomplished through a combination of a site investigation and a sit-down brainstorming session with plant personnel. Table 2 shows the result of this step for a steam plant. Indicated in the table are the source activities, drainage areas within the facility where these sources are located, potential pollutants associated with the source, and a relative measure of the importance of the source for creating receiving water problems.

Contamination potential:

1 = high

2 = medium

3 = low

### *Step 3: Develop Candidate Control Measures*

Develop candidate control measures for consideration that address each of the potential and known sources of pollutants. The last column in Table 2 shows these measures.

**Table 2. Example of Source and Pollutant Identification and BMP Selection for Industrial Facility**

| Source Areas | Drainage Areas | Potential Pollutant | Contamination Potential | Recommended Control Measure |
|---|---|---|---|---|
| Parking lots | 1, 2, 4 | Oil and grease<br>TSS | 2<br>2 | • Inspect and clean catchbasins<br>• Conduct good housekeeping practices |
| Loading docks | 1, 2 | Oil and grease<br>Toxics | 3<br>3 | • Provide mats to cover catchbasins if spill occurs while raining |
| Construction equipment parking | 1, 2 | Oil and grease<br>TSS | 2<br>2 | • Inspect and clean catchbasins<br>• Conduct good housekeeping practices |
| Materials storage | 1 | TSS<br>Metals<br>Toxics | 2<br>2<br>3 | • Sweep after loading and unloading materials from concrete vaults<br>• Place materials with greatest contamination potential under Ferry St. overpass |
| Curing oil storage | 1 | Oil and grease | 2 | • Move drums inside or to a bermed area that is covered |
| Vehicle fueling | 2 | Fuel<br>Oil and grease | 3<br>3 | • None |
| Aboveground fuel storage | 2, 3 | Fuel | 3 | • None |
| Utility pole storage | 2 | PCP1<br>Creosol<br>Metals<br>Oil and grease | 1<br>1<br>1<br>1 | • Determine feasibility of moving poles under Ferry St. overpass |
| Vehicle rinse area | 2 | TSS<br>Oil and grease | 2<br>1 | • Clean sediment trap more often<br>• Consider adding oil/water separator |
| Steam cleaner | 2 | TSS<br>Oil and grease<br>Detergents<br>Toxics | 3<br>3<br>3<br>3 | • Enlarge pad area<br>• Post signs providing employees with proper instructions<br>• Rinse pad after cleaning<br>• Clean oil/water separator more often |

**Table 2. Example of Source and Pollutant Identification and BMP Selection for Industrial Facility *(Continued)***

| Source Areas | Drainage Areas | Potential Pollutant | Contamination Potential | Recommended Control Measure |
|---|---|---|---|---|
| Transformer cleaner | 2 | Mineral oil | 3 | • None |
| | | PCBs | 3 | |
| Sodium hypochlorite storage | 2 | NaOCl | 2 | • Relocate drums inside or to a bermed area that is covered |
| Hogged fuel pipe | 3 | Tannin and lignin | 3 | • Sweep street after heavy winds |
| | | BOD | 2 | • Clean catchbasin more often |
| | | COD | 3 | |
| Sulfuric acid storage | 3 | $H_2SO_4$ | 3 | • None |
| Oil drum storage | | Oil and grease | 3 | • None |
| Ash handling area | 4 | TSS | 2 | • Enlarge the loading area |
| | | pH | 2 | • Improve the loading procedure |
| | | Toxics | 2 | • Clean the catchbasins in the immediate area more often |

### *Step 4: Conduct BMP Evaluation and Selection*

Conduct a BMP evaluation and selection session with plant personnel. Just as in a municipality, involving the right plant personnel in the process is very beneficial. Such involvement allows the plan to reflect their extensive knowledge of the site and industrial activities, and encourages the plant staff to take ownership of the management plan. Often, we have found that personnel have been trying to implement some of the BMPs, and the NPDES permit requirements now give them the impetus to get them more fully implemented. In these sessions, we have sometimes used a formal decision process, while at other times a less formal, but still documentable, discussion of the potential BMPs was used to select BMPs. The focus of BMPs at industrial sites where we have worked has been source control. Compared with municipalities, however, industries tend to be more willing to consider installing or retrofitting structural controls.

### *Step 5: Prioritize BMPs and Develop Monitoring Program*

Prioritize BMPs and develop and implement “monitoring” programs for assessment of effectiveness.

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1. Woodward-Clyde Consultants. 1990. Urban targeting and BMP selection: An information and guidance manual for state NPS program staff and managers. Prepared for U.S. Environmental Protection Agency (May).

2. U.S. EPA. 1993. Handbook: Urban runoff pollution prevention and control planning. EPA/625/R-93/004.

# *A Catalog of Stormwater Quality Best Management Practices for Heavily Urbanized Watersheds*

**Warren Bell**
**City of Alexandria, Alexandria, Virginia**

## Abstract

Various federal and state environmental programs require the use of onsite structural best management practices (BMPs) to control the quality of stormwater discharges from development sites. Space constraints, extremely high property values, soil conditions, and the proximity of other building foundations often preclude the use of conventional stormwater BMPs for infill construction or redevelopment in the intensely builtup centers of major cities, where pollutant loads are usually the greatest. Unconventional solutions must be applied in these heavily urbanized environments.

Alexandria, Virginia, has adopted and published design criteria for several nonconventional BMPs, many of which employ intermittent sand filter technology; some of these BMPs were developed by pioneering jurisdictions throughout the United States; the city's engineering staff devised others:

- Stormwater sand filter basins in widespread use in Austin, Texas, are readily adaptable for large development projects.
- Underground vault sand filters employed in the District of Columbia (DC) allow full economic use of surface areas.
- Double-trench sand filters adopted by the state of Delaware can be placed either in or adjacent to paved areas.
- Simple trench and modular sand filters developed by the city of Alexandria are suitable for small or medium-size sites.
- A peat-sand filter adapted from a Metropolitan Washington Council of Governments design is applicable to situations where high pollutant removal is required.
- Water quality volume detention tanks for use in Alexandria's combined sewer areas capture the most polluted stormwater for later treatment in the wastewater treatment plant.

## The Heavily Urbanized Environment

The U.S. Environmental Protection Agency (EPA) program for National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges envisions the use of onsite structural best management practices (BMPs) to control the quality of runoff from development sites. Many state programs already impose the requirement for onsite BMPs on developers. Under the Virginia Chesapeake Bay Preservation Act (VCBPA), no net increase in pollutants in stormwater runoff is allowable from previously undeveloped sites in Chesapeake Bay Preservation Areas (CBPAs). Runoff from redevelopment sites in CBPAs must contain 10 percent fewer pollutants than existed before redevelopment. In devising a local program to meet these pollutant removal performance requirements, Alexandria confronted the dilemma of which structural BMPs to employ. The entire city is designated as a CBPA. Most of the land is already developed, and large areas are heavily built up, in many cases with lot-line to lot-line structures. Property values are also extremely high. Such conditions exist in the central business districts of most metropolitan areas.

Use of conventional structural BMPs is often impractical in the heavily urbanized environment. Space and cost constraints severely inhibit the use of dry detention ponds and wet ponds. Soil conditions and high water tables in the river valleys where most older cities are located frequently preclude the use of infiltration devices because of the prevalence of marine clays. Unconventional solutions had to be found to remove the pollutants from stormwater runoff created by development activity. Research by the engineering staff of Alexandria's Transportation and Environmental Services Department revealed that very little information is available on how to remove pollutants from runoff in heavily urbanized environments.

## BMP Design Criteria for Heavily Urbanized Areas

The Alexandria engineering staff consulted with jurisdictions throughout the United States where BMPs addressing heavy urbanization are being investigated, then synthesized the information obtained into comprehensive design criteria for local developers. The staff also developed several additional BMPs for use in the city. Design criteria for these BMPs for heavily urbanized areas were published in the *Alexandria Supplement to the Northern Virginia BMP Handbook* in February 1992 (1). The publication is being used by the Virginia Chesapeake Bay Local Assistance Department as a guide for other urban stormwater programs within the commonwealth.

## The Concept of BMPs for Heavily Urbanized Areas

Stormwater quality management in the heavily urbanized environment involves the following activities for the most polluted runoff:

- Collection
- Pretreatment to remove sediments
- Storage
- Treatment to remove pollutants of a specific quantity

In Virginia, the minimum quantity of stormwater to be treated is the first 1/2 in. of runoff from the impervious areas on the site—the water quality volume (WQV). The WQV for each impervious acre is just over 1,800 $ft^3$.

### *Capturing the WQV*

A typical approach for achieving isolation of the WQV is to construct an isolation/diversion weir in the stormwater channel or pipe such that the height of the weir equals the height of the water in the BMP when the entire WQV is being held. When additional runoff greater than the WQV enters the stormwater channel or pipe, it will spill over the isolation/diversion weir, and the extent of mixing with water stored in the BMP will be minimal. The overflow runoff then enters a peak flow rate reducer or exits directly into the stormwater collection system. Figure 1 illustrates this approach.

### *Pretreatment Requirements*

Several conventional BMPs, such as buried infiltration devices, and most unconventional BMPs require some type of pretreatment system to remove excessive sediments, which would result in premature failure of the BMP. Pretreatment mechanisms may be installed either at the point of collection or after separation of the WQV. These mechanisms may be either separate devices or an integral part of the BMP itself.

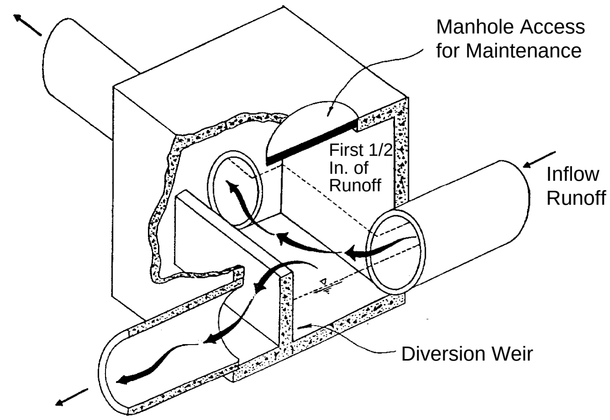


**Figure 1. Typical isolation/diversion structure.**

Water quality inlets (WQIs), or oil-grit separators (OGSs), have been employed for several years for the removal of grit and oil, which are found in large quantities in parking lots and other areas where vehicular traffic is significant. Recent studies by the Metropolitan Washington Council of Governments (MWCOG), however, have established that WQIs provide little or no pollutant and questionable hydrocarbon removal (3).

Sedimentation basins have traditionally been the first step in water or wastewater treatment. Where site conditions allow, presettling basins may provide a low cost approach to removal of sediments, which can clog infiltration devices or filter systems. In situations where space is not a problem, presettling basins may be built directly into the ground. In the heavily urbanized environment, where space utilization is an important economic consideration, underground presettling chambers in vaults or pipe galleries may provide a more feasible solution. Alexandria sizes sedimentation basins using a methodology based on the Camp-Hazen equation, published by the State of Washington Department of Ecology (4).

Grassed filter strips are a common method employed in northern Virginia for removing sediments from stormwater to be treated in infiltration systems. To be effective, the strip must be at least 20 ft wide, have a slope of 5 percent or less (5), and be stabilized.

### *Storage of the WQV*

Following isolation of the WQV and pretreatment to remove sediments and other pollutants, water must be stored until it can be processed in the primary treatment device (up to 40 hours in Alexandria). Creating over 1,800 $ft^3$ of water storage per impervious acre on the site is often the most costly item in the overall BMP system. In some cases, as with sedimentation basins, storage may be combined with pretreatment. In others, separate storage galleries of round or arched-section pipe may be required. Some BMPs for heavily urbanized areas combine pretreatment, storage, and primary treatment in a single underground vault.

### *Treatment of the WQV*

Most of the BMPs described in this paper employ intermittent sand filters. Originally developed during the 1800s for treating both water supplies and wastewater, intermittent sand filters have regained popularity for use in the treatment of small wastewater flows (6).

Austin, Texas, and the state of Florida pioneered the use of sand filters in the treatment of stormwater runoff. Alexandria uses the Austin sand filter equation derived from Darcy's Law by the Austin Environmental and Conservation Services Department to size sand filters (2):

$$A_f = I_a H d_f / k(h+d_f)t_f$$

where

$A_f$ = surface area of sand bed (acres or square feet)
$I_a$ = impervious drainage area contributing runoff to the basin (acres or square feet)
$H$ = runoff depth to be treated (feet)
$d_f$ = sand bed depth (feet)
$k$ = coefficient of permeability for sand filter (feet per hour)
$h$ = average depth (feet) of water above surface of sand media between full and empty basin conditions (half maximum depth)
$t_f$ = time required for runoff volume to pass through filter media (hours)

Based on long-term observation of existing sand filter basins, Austin uses k values of 3.5 ft/day for systems with full sedimentation pretreatment and 2.0 ft/day for systems with only partial sedimentation pretreatment. Alexandria has also adopted these values. Both Austin and Alexandria use a BMP drawdown time ($t_f$) of 40 hours. With these constants, the equation for sand filter systems with full sedimentation protection reduces to

$$A_{f(FS)} = 310 I_a d_f/(h+d_f),$$

where $A_f$ is in cubic feet and $I_a$ is in acres.

For sand filter systems with partial sedimentation protection, the equation reduces to

$$A_{f(PS)} = 545 Ia d_f/(h+d_f),$$

where $A_f$ is in cubic feet and $I_a$ is in acres.

## Descriptions of BMPs for Heavily Urbanized Areas

The BMPs discussed below should not be thought of merely as drainage structures. They are low technology treatment works that use water and sewage treatment technology from the late 19th century. Treatment works cannot always be made to function by gravity flow, although it is usually desirable from a cost-effectiveness standpoint.

### *Surface Sand Filter Basin Systems*

Austin, Texas, was a pioneer in the use of intermittent sand filtration systems for treating stormwater runoff. The Austin program is managed by the Environmental and Conservation Services Department, which has published design criteria in their *Environmental Criteria Manual* (2).

Typical intermittent sand filters employ an 18- to 24-in. layer of sand as the filter media underlain by a collector pipe system in a bed of gravel. A layer of geotechnical cloth separates the sand and gravel to keep the sand from washing into voids in the gravel. Austin pretreats the stormwater runoff in a sediment trapping structure to protect the filter media from excessive sediment loading.

Figure 2 is a centerline cutaway of one Austin sand filter configuration. In this system, the sedimentation structure is a basin designed to hold the entire WQV, then release it to the filtration basin over an extended drawdown period. An alternate design allows use of a smaller sedimentation chamber but requires increasing the filter size to compensate for increased clogging of the filter media. While the system shown uses concrete basins, a sediment pond and a geomembrane-lined filter built directly into the ground may be used where terrain and soil conditions allow. The Austin sand filter systems are most appropriate for large developments covering several acres.

Austin has monitored the performance of their sand filters for several years and currently recognizes up to 60 percent phosphorus removal efficiency based on these studies (7). Alexandria is currently recognizing a 40 percent phosphorus removal rate pending further sand filter monitoring results by Austin and the District of Columbia. (Phosphorus is the "keystone pollutant" used to measure compliance with the VCBPA.)

### *Underground Vault Sand Filter Systems*

Truong developed a stormwater quality sand filtration system in an underground vault (8). Over 70 of the structures have been installed since 1987. Figure 3 is a centerline cutaway of the original concrete vault DC sand filter. DC sand filters may be placed underneath parking lots, alleys, or driveways, taking up no usable space on the surface. This is an important advantage in the heavily urbanized environment. Truong believes that

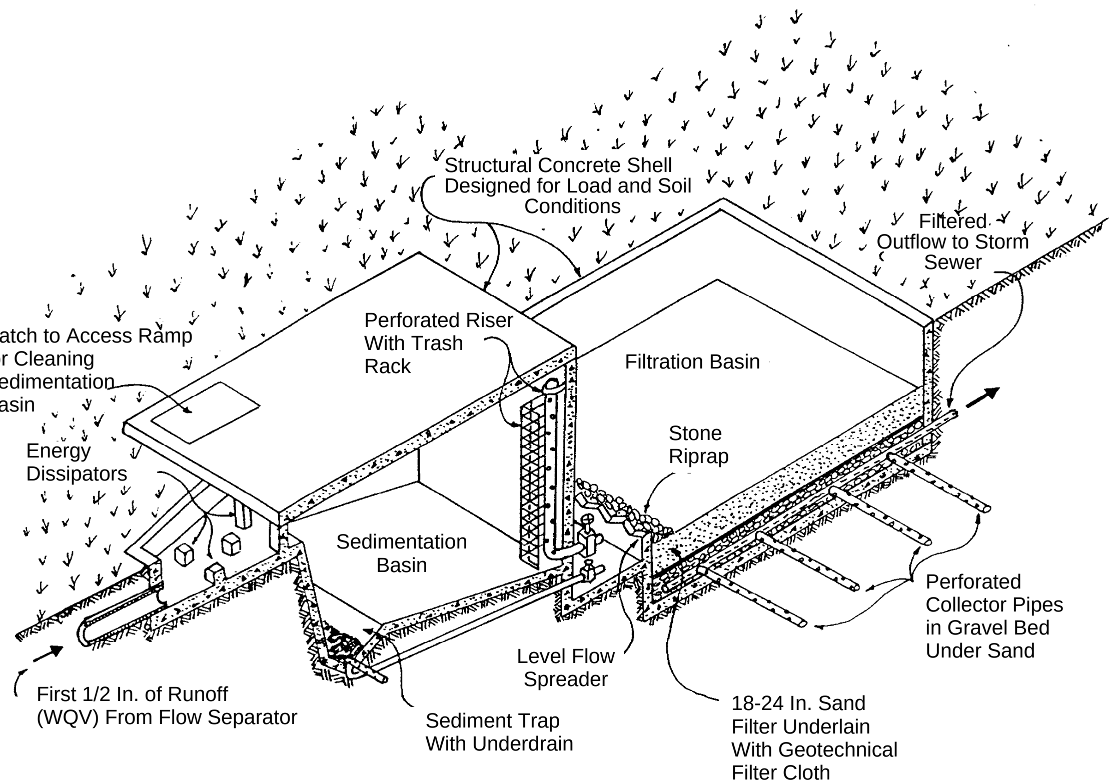


**Figure 2. Austin basin sand filter system.**

this system works best on watersheds with 1 acre or less of impervious cover.

The DC sand filter is a three-chamber gravity-flow system. The first chamber and the throat of the second chamber contain a permanent pool that traps grit and floating organic material, such as oil, grease, and tree leaves. A submerged rectangular opening at the bottom of the first dividing wall connects the two parts of the pool. The second chamber also contains a 24-in. deep sand filter underlain by a layer of geotechnical fabric and collector pipes in gravel. A top layer of plastic-reinforced geotechnical filter cloth held in place by a 1-in. layer of gravel is provided above the sand to compensate for the smallness of the sedimentation chamber.

New runoff entering the structure causes the pool to rise and overflow onto the filter. After percolating through the sand, the treated water enters the underdrains and flows out into the third chamber, or clearwell. The clearwell conveys the treated water to the storm sewer or drainage system. If possible, this BMP should be configured to allow gravity outflow; however, in instances where filters must be placed below the storm drainage system elevation, such as under the entrance driveway to a parking garage, a sump pump must be used.

The trash and hydrocarbon water trap in the first chamber must be pumped out and refilled with clean water every 6 months for proper functioning. Every 3 to 5 years, the top filter cloth layer and gravel must be removed and replaced because of fine sediment clogging. Placement of the second chamber manhole directly above the center of the filter allows the corners of the cloth to be peeled up and bound together to form a bag that can be lifted out as a unit.

The District of Columbia Environmental Regulation Administration is conducting a program of monitoring to establish the actual removal rates of this system. As of this writing, no data are available.

The Austin partial sedimentation sand filter may also be placed in underground vaults. Figure 4 shows a modified vault design developed by Alexandria from both Austin and District of Columbia methodologies. The Austin approach uses a gabion wall to separate the partial sedimentation chamber from the filter area. The gabion absorbs energy and provides initial filtration. Heavy sediments are deposited in this first chamber to dry out between storms. The filter is exactly like that used in the DC sand filter system.

### *Double Trench Sand Filter Systems*

Shaver developed a surface sand filter system for use in Delaware (9). The Delaware sand filter is intended to be an in-line facility processing all stormwater exiting the site until it overflows.

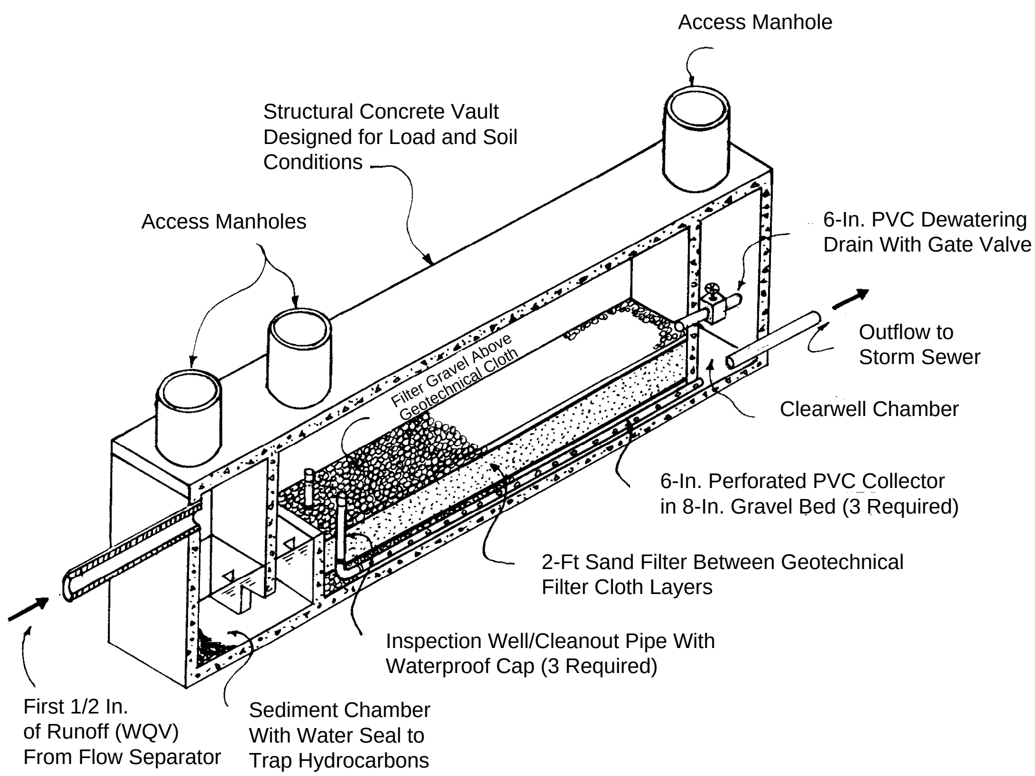


**Figure 3. DC underground vault sand filter.**

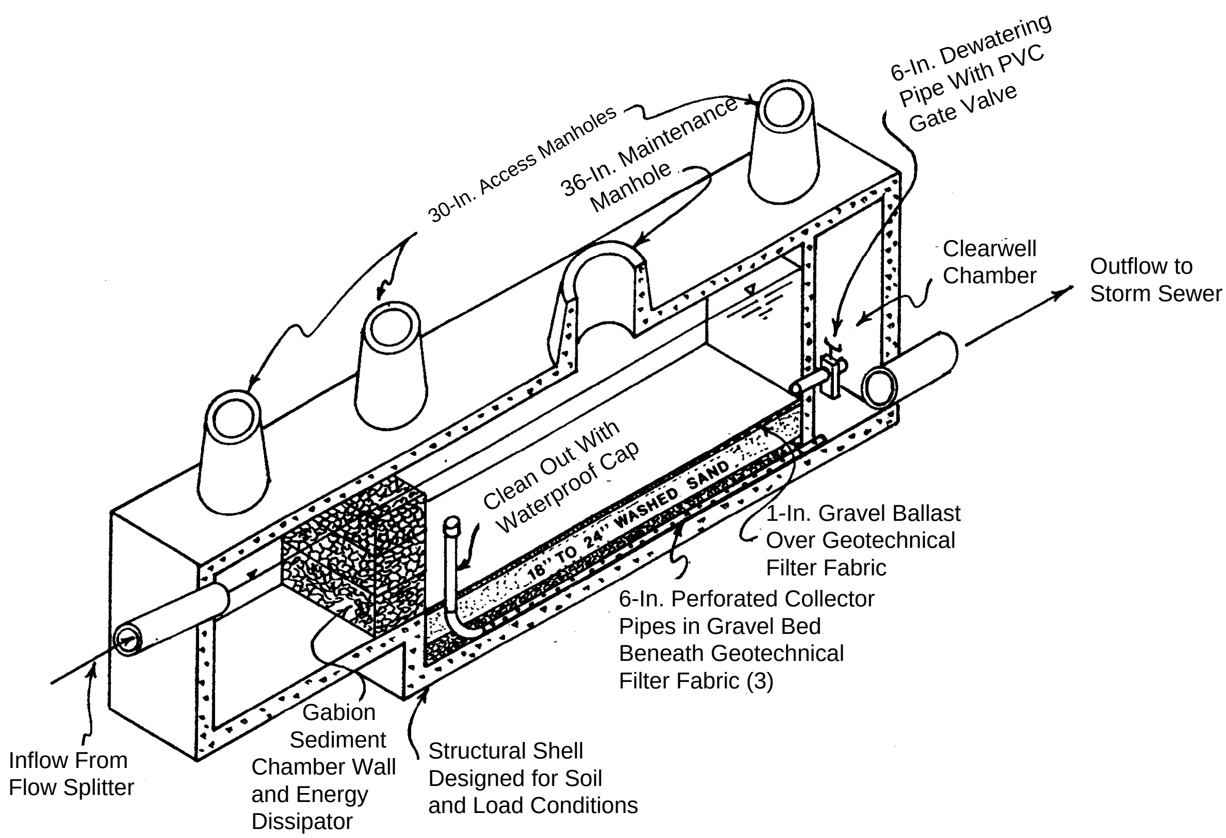


**Figure 4. Dry vault stormwater sand filter.**

Figure 5 is a schematic drawing of the Delaware sand filter system. The concept uses two parallel waterproof trenches connected by close-spaced wide notches in the top of the wall between them. The trench adjacent to the site being served is the sedimentation chamber. Polluted stormwater must be conveyed to the chamber in enclosed storm-drain pipes. The permanent pool in the sedimentation chamber inhibits resuspension of particles that were deposited in earlier storms and prevents the heavier sediments from being washed into the filter chamber. As new stormwater enters the system, the permanent pool overflows through the weir notches and onto the filter as sheet flow to prevent scouring out the sand.

The second chamber contains an 18-in. sand filter that is always fitted with a solid cover. No underdrain piping is provided. Water percolates through the sand and escapes from the filter through a geotechnical cloth-covered grate at the downhill end of the filter chamber.

Four Delaware sand filters were constructed in Alexandria during 1992. The first two systems served small parking lots and were built according to the original Delaware design. The third application, involving two separate filters, was used to treat runoff from a large (1.7 acre) parking lot. The high cost of steel grates and covers led the developer's consultant to propose moving the filter off the lot and providing slotted curb ingress and precast concrete lids. Premature failure of one of the filters led the owner to install a collector pipe in gravel below the sand layer. This design is shown in Figure 6.

Although the filters illustrated are contained in reinforced concrete shells, these systems may be installed in any waterproof container that will bear the wheel loads or soil pressures involved with the particular application; molded fiberglass or other plastic materials would work well. Delaware sand filters made of timber lined with rubberized roofing material have been proposed for use on temporary parking lots for development sales offices.

Delaware does not rate these systems for nutrient removal efficiency. Delaware has made a determination, however, that when treating the first 1 in. of runoff, this sand filter provides 80-percent suspended solids removal, as required by state environmental regulations (9).

### *Stone Reservoir Trench Sand Filter Systems*

The filter system concepts embodied in the Austin and District of Columbia designs may be readily adapted for small and less complex applications. Alexandria's engineering staff has developed a simple trench sand filter for use on such projects as townhouses or small commercial developments in areas where infiltration devices are not practicable.

Figure 7 is a schematic drawing of a stone reservoir trench sand filter. The system is constructed in an excavation lined with impervious geomembrane (such as EPDM roofing material) sandwiched between protective layers of filter cloth. The bottom of the trench contains a simple sand filter that is connected to the storm sewer. The upper part of the system is built the same as an infiltration trench designed to treat the first 1/2 in. of runoff. Placement of perforated pipes in the stone reservoir greatly increases the voids available for storage.

Dispersed overland sheet flow is treated in a grassed filter strip before entering the system. The reservoir is further protected from sediment clogging by a layer of geotechnical filter cloth 6 in. beneath the top surface of

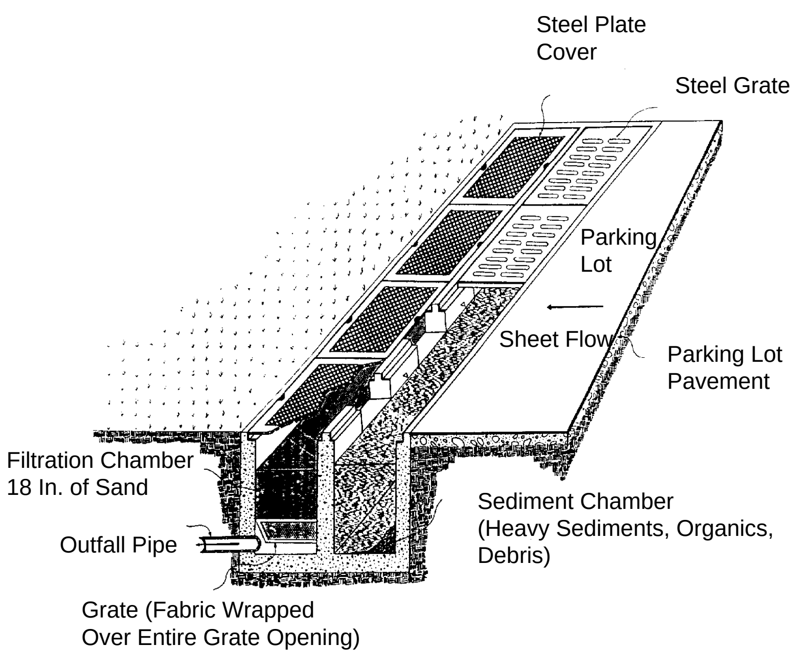


**Figure 5. Delaware sand filter with grated inlets.**

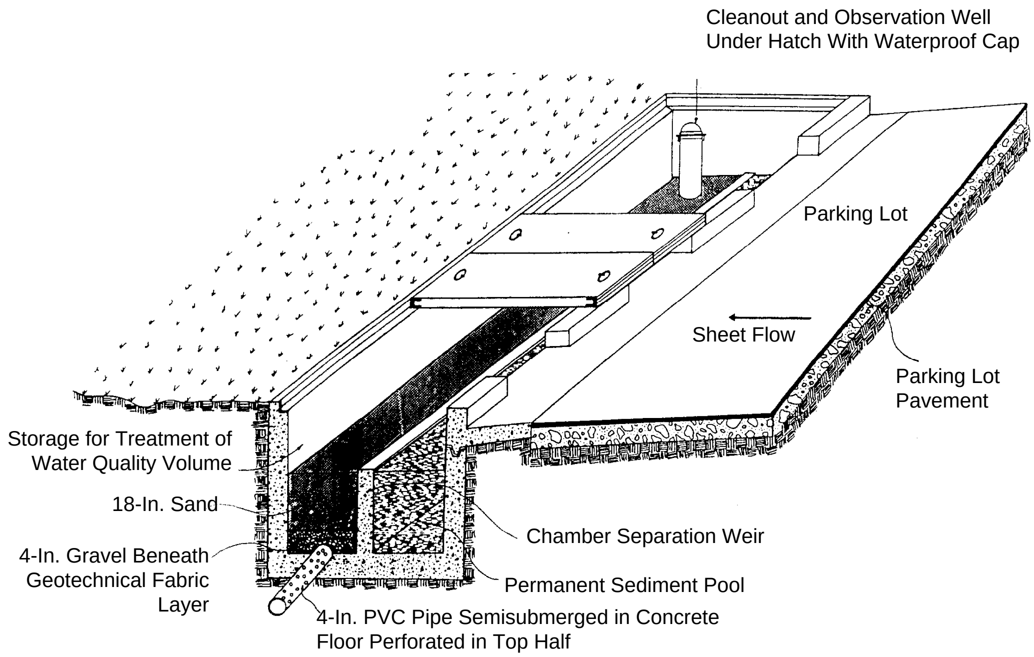


**Figure 6. Slotted curb Delaware sand filter.**

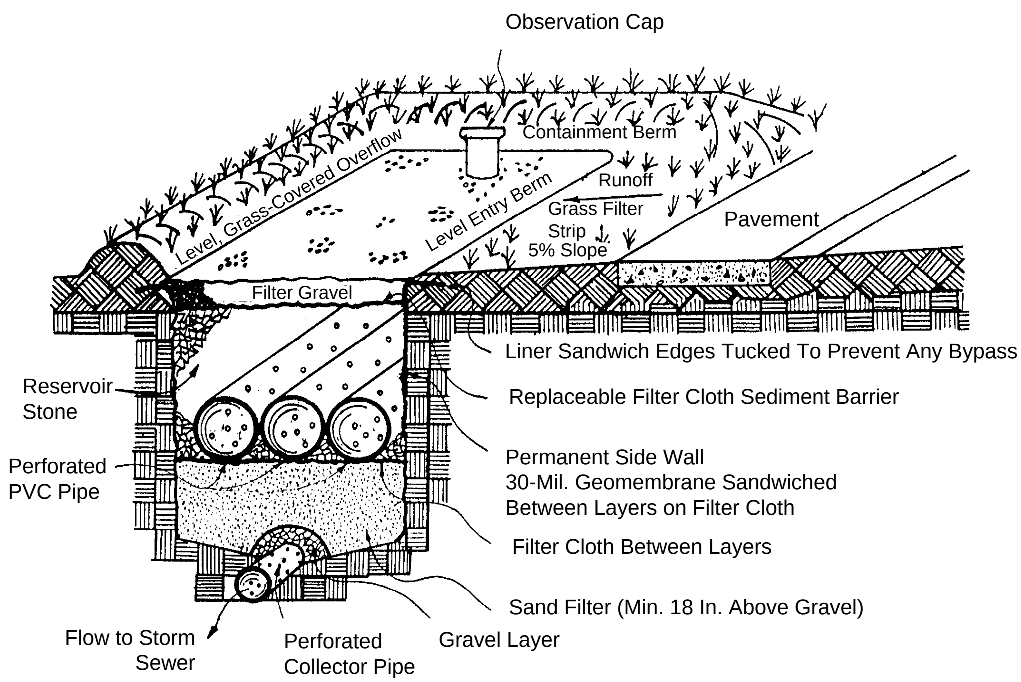


**Figure 7. Stone reservoir trench sand filter.**

the aggregate. The WQV flows into the reservoir until the voids in the rock and perforated pipes are completely full. Any overflow is directed to the storm sewer. Runoff collected in the reservoir filters down through the sand to the collector pipe, from which it is conveyed to the storm sewer.

Trench sand filter systems should have the same removal efficiency as an Austin sand filter.

## *Peat-Sand Filter Systems*

Because of their high pollutant removal capabilities, simple design, low-maintenance, and affordability, peat-sand filters (PSFs) are potentially effective in heavily urbanized areas. A stormwater “end-of-pipe” PSF system was scheduled to be constructed in Montgomery County, Maryland, in the summer of 1993. MWCOG staff participated heavily in the development of this project.

Figure 8 is a centerline cutaway of a stormwater PSF system concept developed by the Alexandria engineering staff. It combines features of the Austin sand filtration system with the PSF design proposed by John Galli of MWCOG for use in the Montgomery County application (10). The Alexandria concept is intended to operate as an off-line system treating the WQV from each storm. Any additional detention required for stormwater quantity restrictions should be provided separately downstream of the PSF system. PSFs would be appropriate for commercial developments for which a high pollutant removal is required or for end-of-pipe treatment of entire storm sewer watersheds.

The sedimentation basin design is essentially the same as that of the Austin sand filter. Because PSF systems cannot normally operate during the more severe winter months of the mid-Atlantic region, however, a gate-valve equipped bypass is provided to divert flow from the basin directly to the storm sewer. The invert of this pipe is placed at an elevation that will detain a permanent pool in the basin averaging at least 4 ft deep. In effect, this configuration converts the sedimentation basin to a small extended detention/wet pond during the winter months. As with the Austin sand filter, the basins may be either walled with concrete, as shown, or, if soil conditions permit, be constructed as soil structures.

The filtration basin is basically the Austin design with the sand filter enhanced by adding a 12- to 18-in. thick surface layer of hemic or fibric peat, a layer of calcitic limestone (for greater phosphorus removal), and a 4-in., 50:50 well-mixed layer of peat and fine-medium grain sand atop the normal filter sand and collector underdrains. A nutrient-removing grass-cover crop must be planted and maintained in the top of the peat layer. (PSFs will not function in underground applications because anaerobic conditions would develop.)

The system shown is designed for gravity flow. In situations where the terrain does not provide sufficient relief, pumps must be added to move the stormwater between basins.

Based on information provided by MWCOG (10), the Alexandria engineering staff estimates that their PSF design should have a phosphorus-removal efficiency approaching 90 percent during the months in which the filter is in operation. Assuming that the filter would be bypassed from mid-December to mid-March in the mid-Atlantic region, the annual phosphorus removal efficiency of the overall system, including the small extended detention/wet pond, is estimated at 70 percent.

### *Water Quality Volume Storage Tanks*

This concept involves the collection and storage for later treatment in the wastewater treatment plant of the WQV from each storm. WQV storage tanks are used on all developments or redevelopments that require a BMP within Alexandria's combined sewer watersheds. Figure 9 shows a centerline cutaway of a WQV storage tank. The stored water is released into the combined or sanitary sewer system by telemetry-controlled pumps or automatic valves that ensure that none of the WQV escapes while combined sewer overflows into streams

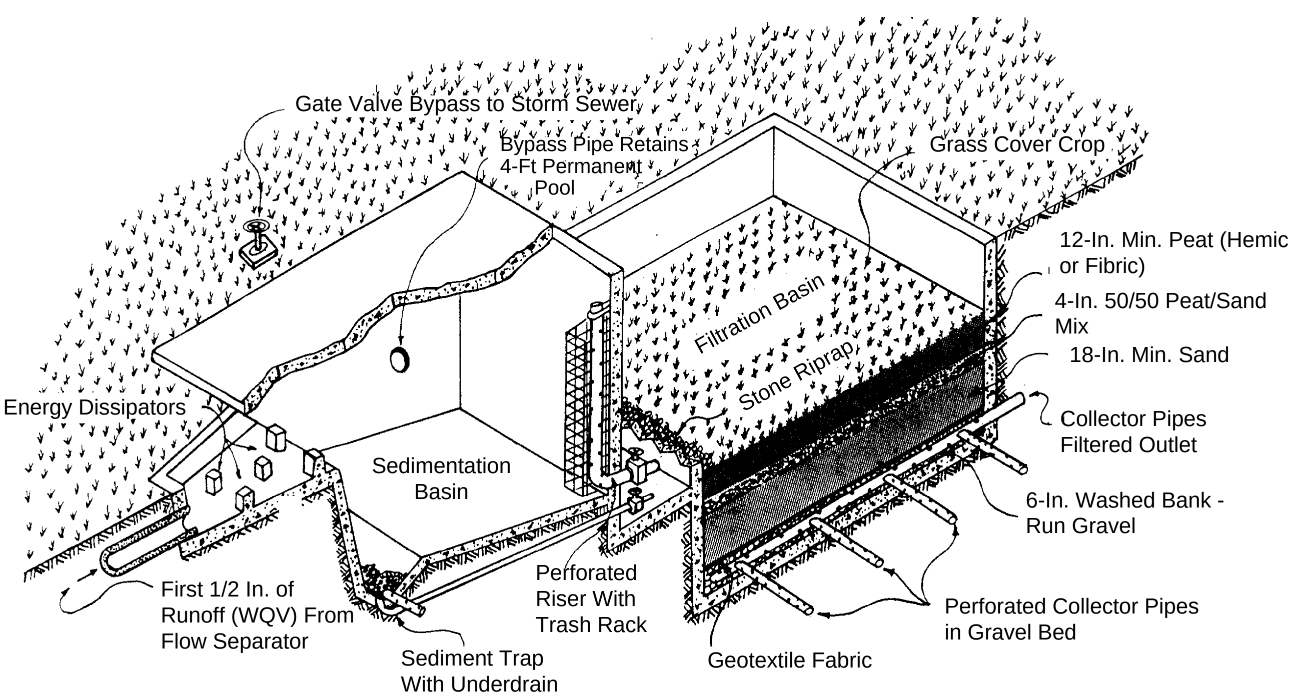


**Figure 8. Stormwater peat-sand filter system.**

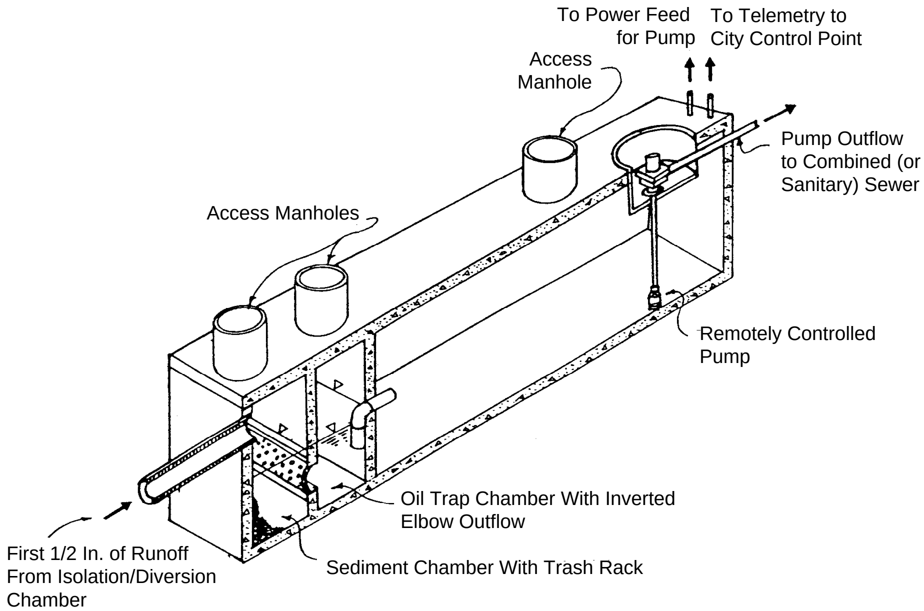


**Figure 9. Water quality volume storage tank.**

are occurring or in periods when inflow and infiltration are taxing the capacity of the wastewater treatment plant. This approach conforms to EPA's August 19, 1989, National Combined Sewer Overflow Strategy, which requires establishment of a high-flow management plan that maximizes the capacity of the combined sewage system for storage and treatment.

The tank shown in Figure 9 has a water quality inlet to provide sediment and petroleum hydrocarbon removal before the runoff is allowed to enter the storage tank. The inlet must be pumped out and refilled with clean water every 6 months for proper functioning.

WQV storage reservoirs may be either prefabricated tanks or vaults fabricated on site from such materials as Portland cement. Either single or multiple tanks may be employed. Although originally developed for use in combined sewer watersheds, WQV storage tanks may be applied in other situations where WQV runoff will not be routed into the storm sewer (e.g., landscaping irrigation systems or "gray water" toilet flushing systems).

When WQV water is discharged directly into a combined or sanitary sewer or used in gray-water flushing systems, the pollutant removal efficiency of the system becomes that of the receiving wastewater treatment plant. The phosphorus removal capacity of such plants is typically in the 95- to 100-percent range. When the WQV water is reused and retained on site for landscape irrigation, pollutant removal may approach 100 percent if the water is not allowed to escape from the site.

## Challenges in Development and Use of BMPs for Heavily Urbanized Areas

The field of BMPs for heavily urbanized areas is in its infancy. The next few years must bring much wider use of this technology if the pollutant removal objectives of the NPDES stormwater program and other federal and state clean water initiatives are to be met. Several significant challenges need to be addressed.

### *Reduce Construction Effort and Costs*

The construction cost for Austin sand filters serving projects with approximately 1 acre of impervious cover ranged from $13,000 to $19,000 in 1990 (1). The cost of DC sand filters was approximately $35,000 per impervious acre when the filters were first introduced but has since fallen to approximately $12,000 to $16,000 through the introduction of precasting and the maturity of the design (11). The large, slotted-curb Delaware sand filters recently constructed in Alexandria cost approximately $40,000 to serve 1.7 acres of impervious cover. This was, in essence, a prototype facility, and costs are expected to fall in a manner similar to the DC sand filter costs as contractors and engineers become familiar with the technology.

Applying prefabrication and modular concepts, especially for smaller projects, should further reduce construction effort and costs. Alexandria and the District of Columbia are exploring the rationalization of sand filter vaults in circular sections with manufacturers of aluminized corrugated pipe and fiberglass underground tanks. The pipe manufacturer has indicated that filters that would serve up to 1 acre of impervious cover could be prefabricated in a shop and delivered as a unit to a job site. The District of Columbia has also developed a sand filter in a standard precast sewer manhole. By introducing the runoff through a large catch basin with a hooded outlet, the addition of a 6-ft manhole with a sand filter in the bottom makes a BMP suitable for treating the runoff from approximately 5,200 $ft^2$ of impervious cover; 8-ft manhole filters can serve approximately 10,000 $ft^2$. Alexandria is examining the feasibility of adapting standard large highway precast curb inlets as the shells of both Delaware sand filters and underground vault sand filters. Storage of runoff awaiting filtration in arched corrugated-pipe galleries appears to be a promising approach in areas where storm sewers are too shallow to employ vault filters without pumping. Much more innovation is still needed for heavily urbanized areas.

One of the major costs of BMPs for heavily urbanized areas is creating a container to store the runoff before it undergoes treatment. More studies need to be performed characterizing different types of runoff to determine whether all sites need similar treatment. For instance, pollutants in runoff strictly from roofs may be concentrated in a smaller amount of “first flush.” Pollution concentration versus time studies of roof water might well establish that treatment of a smaller amount of runoff would meet pollutant removal performance requirements. This development would likely have a significant impact on costs.

### *Reduce Maintenance Requirements and Costs*

All BMPs for heavily urbanized areas require significant maintenance. Permanent pools require pumping out on a periodic basis (currently twice per year in Alexandria) to remove accumulated sediments and trapped hydrocarbons. As discussed above, sand filters require the replacement of the top few inches of sand or overlying layers of geotechnical cloth every 3 to 5 years. Trash must be removed from all BMPs as it accumulates to prevent premature clogging. Special care must be taken to ensure that sand filter systems are not placed in service before all open areas are stabilized with vegetation. Otherwise, the filters might quickly clog with topsoil, as occurred with one of Alexandria’s Delaware sand filters. Trash screens need to be included in all designs to preclude the intrusion of materials into filter chambers that can cause premature failures. The provision of ready maintenance access is an absolute necessity. The initial cost/maintenance cost tradeoff must be carefully examined during the BMP design process.

### *Enhance Removal of Pollutants*

The 1990 Austin report on removal of pollutants by that city’s sand filters is the only scientific data available at present on long-term monitoring of such systems (7). The reported results are encouraging, but more monitoring data is needed to assess the impact of such factors as acid rain and variations in chemical content of the filter media on performance before the Austin experience can be generalized for application to other regions of the country.

While Austin reports very promising phosphorus removal values, enhancing the nitrogen and perhaps the heavy-metal removal efficiencies of BMPs may develop as a more pressing need as NPDES runoff monitoring data become available. One avenue that appears promising is the employment of a wet gravel filter component to introduce biological activity in the treatment process, an approach that is already being used to treat individual home sewage in Anne Arundel County, Maryland (12). The District of Columbia is considering adding a layer of activated carbon to a sand filter to assess the benefits through monitoring. BMPs for heavily urbanized areas represent a field that is ripe for additional innovation. Universities should take a more active role in developing BMP technologies for these areas.

### *Spread the Technology*

Currently, the use of BMPs for heavily urbanized areas is limited to a relatively small area in the mid-Atlantic states, the Austin area in Texas, and the state of Florida. The technology is applicable to all areas of the country where pollution in stormwater runoff must be controlled under the NPDES permit program. Information on these BMPs needs to be disseminated throughout the country by EPA and other environmental agencies so that the technology is available to all parties who are wrestling with the problems of attaining NPDES compliance. This paper was written to facilitate that process.

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# *Postconstruction Responsibilities for Effective Performance of Best Management Practices*

**Joseph J. Skupien**
**Somerset County Engineering Department, Somerville, New Jersey**

## Abstract

Effective performance of best management practices (BMPs) is vital to achieving the high goals and justifying the equally high estimated costs of urban runoff management. This paper identifies inspection, maintenance, and performance monitoring as three key postconstruction activities for ensuring correct and continued performance of BMPs. These activities are equal in importance to planning, design, and construction BMPs.

The paper demonstrates how failure to meet inspection and maintenance BMP responsibilities not only leads to diminished BMP performance but may also create new health and safety threats that exceed those the BMPs were intended to prevent. It further demonstrates how such a result represents both a failure to realize a gain on the resources already invested in BMPs and the cause of significant additional expenditures.

The paper also describes the key components of a successful postconstruction inspection and maintenance program, including the need for self-evaluation and feedback components to inform planners, designers, construction contractors, and maintenance personnel about ways to reduce or facilitate future maintenance. Additionally, the paper emphasizes the importance of a stable source of program funding and discusses various methods for achieving it.

Finally, the paper emphasizes the need for accurate, scientific monitoring and reporting of BMP performance to achieve optimal BMP designs and expand the ability to address urban runoff impacts on a regional or watershed basis.

## Introduction

One of the top priorities of any stormwater management program is the effective performance of structural best management practices (BMPs). Effective BMP performance not only helps ensure that the program's goals are accomplished but also represents a positive return on the time, effort, and materials invested in the structural BMP's planning, design, and construction. To achieve such performance, however, everyone involved with the stormwater management program must fulfill several key responsibilities before, during, and after construction.

Before construction, these responsibilities include the development by program managers of design standards and practices that are both accurate and practical. Designers must use these standards and practices to produce construction drawings that accurately convert their ideas into a tangible structure. Using these drawings, construction contractors must create a durable structure that meets the designers' requirements and is true to the regulators' intentions.

While stormwater management remains a relatively new field, the results to date of these relatively short-term preconstruction activities have been greatly improved by several factors, including the maturation of older flood control programs; the continued growth of hydrologic and hydraulic databases, design methods, and training programs; and the implementation of formal construction inspection programs. Other factors that have assisted in the improvement of regulatory, design, and construction activities include the continued development and greater availability of computer software and hardware and the greater level of construction experience and capability. As a result, the ability of program managers, designers, and construction contractors to meet their responsibilities for effective BMP performance has increased significantly in recent years. Furthermore, these improvements have helped to kindle further interest and involvement in stormwater management.

In addition to planning, design, and construction responsibilities, however, three key areas of responsibility must be met once construction has been completed and the structural BMP has been put into operation. These responsibilities consist of the inspection, maintenance, and monitoring of the structural BMP. For the purposes of this paper, these three activities are defined briefly as follows:

- *Inspection:* Periodic observation and evaluation of a structural BMP and its individual components by qualified personnel to determine maintenance needs.
- *Maintenance:* Periodic preventative and corrective measures taken by qualified personnel to ensure safe, effective, and reliable BMP performance.
- *Monitoring:* Extended observation and evaluation of BMP performance by qualified personnel to determine effectiveness and improvement needs.

Of the three activities, inspection and maintenance are the most well established in terms of BMPs, while monitoring represents a somewhat more recent aspect of stormwater management. More complete descriptions of each activity and their growing importance is presented in later sections of this paper. For now, it is important to note that each activity represents a long-term, ongoing responsibility carried out after the shorter term planning, design, and construction efforts have been completed. It is also important to note that BMPs for inspection, maintenance, and monitoring have not received the same level of attention typically devoted to planning, design, and construction. While lack of adequate funding may be a cause, the reasons for this imbalance are generally unclear. This is unfortunate, because such an imbalance may critically affect the long-term success of stormwater management programs and regulations. Possible reasons include the ongoing, long-term, and somewhat routine nature of inspection and maintenance in particular, which may not offer either the intellectual and creative challenge of planning and design or the immediacy of construction. Additional reasons may be an unacknowledged reluctance to confront the reality of current planning, design, and regulatory efforts (particularly the negative aspects of that reality), or the failure to fully appreciate the importance of BMPs in regard to inspection, maintenance, and monitoring and the serious consequences of their prolonged neglect.

Regardless of the reasons, it is apparent that BMPs for inspection, maintenance, and monitoring have suffered the neglect typical of long-term, ongoing activities. As noted above, this neglect has critical implications for the long-term success of efforts to manage stormwater, particularly through the use of structural BMPs. In an effort to correct this problem, this paper presents information emphasizing the importance of and need for BMPs in inspection and maintenance and describes the key components of a comprehensive inspection and maintenance program. Additionally, the paper highlights the increasing need for monitoring as a means to improve BMP performance and effectiveness and to reduce required inspection and maintenance efforts.

## The Importance of BMP Inspection and Maintenance

A common requirement of virtually all stormwater structures, particularly those that encounter various weather conditions, is their need for periodic inspection and maintenance. While these needs may be obvious in a general sense, the particular importance of inspection and maintenance for structural BMPs needs to be stressed.

Perhaps the most recognizable reason is the need to reliably and consistently achieve the performance levels required by the stormwater management program and designed into the BMP. For example, a BMP that relies on the temporary storage of stormwater runoff to achieve required peak outflow or pollutant removal rates must be periodically cleaned of accumulated sediment and debris to maintain required storage capacity and prevent re-suspension of captured pollutants. The outlet structures at these facilities must also be periodically cleared of accumulated debris to maintain discharge rates at required levels. Maintenance of vegetation is also important, particularly for those BMPs that use the vegetation for pollutant filtration and/or uptake. This maintenance can range from mowing, seeding, and fertilizing turf grass areas to ensure stability and prevent erosion to harvesting wetland vegetation to promote and manage growth.

The maintenance described can also be viewed as an effective means of ensuring a positive return on the time, effort, and materials invested in the planning, design, and construction of a BMP. The total amount of this investment for a single BMP can be considerable, with total construction costs exceeding $50,000 and total project costs exceeding $100,000. Failure to adequately inspect and/or maintain such a facility can lead to ineffective performance, structural failure, and, consequently, a failure to realize a return on the investment. It is generally recognized that the cost of providing comprehensive water quality protection may be considerably greater than our present ability to pay for it. In such cases, we must strive to achieve the greatest possible return on the resources we do invest in such protection.

Perhaps the most important need for BMP inspection and maintenance is the need to avoid the health and safety threats inherent in their neglect. The foremost of these threats is the potential for structural failure, which can rapidly release stored waters and flood downstream areas, causing property damage, injury, and even death. The fact that this flooding threat would not exist if the BMP had not been constructed further highlights the need for proper inspection and maintenance to prevent it from ever occurring. Another health and safety threat from maintenance neglect is mosquito breeding, which can threaten a broad area in the general vicinity of the BMP. Other undesirable insects, animals, and odors can also result from maintenance neglect, adversely affecting those who must live or work nearby. In all such cases, the BMP can actually have worse environmental impacts than those it was originally constructed to prevent.

A final reason for effective BMP inspection and maintenance lies in preserving and nurturing the community and political support that stormwater management efforts have gained to date. Such continued support is vital to the success of our stormwater management efforts, particularly because much of the solution to stormwater pollution lies in source controls and lifestyle changes that the public will be asked to adopt. We cannot count on even passive public support, however, let alone active public involvement in nonstructural programs, if we are unable to create and maintain structural BMPs that are community assets rather than liabilities. Any support that we now have or hope to generate in the future will quickly be lost if we allow structural BMPs to become aesthetic nuisances or safety hazards due to a lack of adequate inspection and maintenance.

## Comprehensive Inspection and Maintenance: An Overview

The key components of a comprehensive inspection and maintenance program for structural BMPs are described below. The exact character of each component and the manner in which it is implemented depends on the specific economic, political, environmental, and social characteristics of the community in which the program functions.

### *Official Inclusion of Inspection and Maintenance in Overall Stormwater Management Program*

BMP inspection and maintenance should not be an afterthought but should be included from the beginning in the community's overall stormwater management program. As the overall program develops, determining how (and how often) inspections and maintenance efforts are performed is as important as determining allowable peak outflow rates and extended detention times. To ignore this fact is to invite eventual program failure through diminishing BMP performance and increasing health and safety threats. To ensure a secure role for inspection and maintenance in the overall stormwater management program, both the importance of inspection and maintenance and the ways in which they are achieved should be officially included in any implementing ordinances, resolutions, or laws establishing the overall program.

### *Sufficient and Stable Funding*

Because BMP inspection and maintenance requires specific actions by qualified personnel, the availability of sufficient and stable funding may be the single most important component of a comprehensive program. The best intentions, talent, and equipment cannot overcome a paucity of funds, nor can regular, consistent inspections and maintenance be achieved if funding levels are erratic and/or uncertain.

Therefore, during the development of the overall stormwater management program, a stable source of funding for inspection and maintenance must be identified and formalized. This may include the use of general or specialized tax revenues, dedicated contributions from land developers or owners, and/or permit fees from those creating the need for the structural BMP. Funding may also be secured through the creation of a stormwater utility, which would provide BMP inspection and maintenance services funded by fees paid by those within the utility's service area. While the creation of a stormwater utility requires a significant amount of effort to organize and operate, several successful stormwater utilities have been created throughout the country in recent years.

### *Adequate Equipment and Materials*

Having sufficient equipment and materials is particularly important for BMP maintenance efforts, which involve the regular performance of preventative maintenance activities such as grass mowing and debris removal and the prompt execution of emergency repairs and restorations. The long-term, repetitive nature of the preventative activities, in particular, demonstrates how a positive return can be quickly achieved from investments in equipment that expedite maintenance efforts and in materials that prolong the life of BMP components.

Fortunately, due in part to the basic nature of stormwater and its management, the character of the equipment necessary to conduct most maintenance efforts is not particularly complex or specialized. Instead, standard and relatively simple equipment such as lawn mowers, shovels, rakes, compressors, and trimmers can be used to perform the majority of maintenance tasks. This helps simplify the selection and acquisition process and keeps costs at more manageable levels.

### *Trained and Motivated Staff*

Similar to equipment needs, many BMP maintenance tasks are not particularly complex or specialized. This means that, under most circumstances, program staff can be assembled from a relatively large labor pool, either directly by a public agency performing maintenance in house or by a contractor hired to provide such services. These factors, however, should not diminish the need for thorough training of maintenance staff. This has become increasingly true in recent years as the role of structural BMPs expands to provide higher levels of stormwater treatment and more comprehensive control of runoff rates. This has led to increasingly sophisticated facilities containing specialized vegetation and diverse habitats that require management as well as maintenance. This trend is expected to continue, further emphasizing the need for thoroughly trained staff.

The importance of motivation and enthusiasm must also be emphasized. Unfortunately, the repetitive and relatively simple nature of many BMP maintenance tasks can lead to indifferent staff performance. In addition to poor overall results, this indifferent attitude can also be dangerous, particularly for those staff members operating mowing or cutting equipment that, however simple, demands concentration and care. Indifference and a lack of enthusiasm can also stifle creativity, which is essential if improved and/or less costly maintenance techniques are to be honed from existing ones. Finally, experience has shown that the vegetated, "living" character of most structural BMPs requires a certain interest and concern on the part of maintenance staff (qualities that are evident in most successful gardeners) if proper maintenance, performance, and aesthetic levels are to be achieved.

Therefore, it is essential for maintenance staff to have an interest in the overall success of the BMP. One way that this may be accomplished is by having the long-term maintenance of a given BMP performed by the same maintenance crew, which then becomes the sole group responsible for its success or failure. Such "ownership" of the BMP helps promote more direct interest in its condition and a greater effort to maintain it.

In addition, competent BMP inspection, particularly of larger, more complex structures and dams, requires a high degree of skill, experience, and knowledge. Often, such levels require that some of the inspections be conducted by a licensed professional engineer who has a background in geotechnical and structural engineering. Other necessary skills may include biology or plant sciences, particularly if the BMP includes diverse vegetation and habitats. Obviously, the training required for such inspection personnel is more rigorous and the number of qualified personnel available to the program will be less. Finally, the training provided to maintenance workers should, in part, be directed at making them informal inspectors as well. When maintenance workers are trained and motivated to spot and report such problems as sloughing or settling of embankments, surface erosion, animal burrows, and structural cracks, repairs can be performed more promptly and with less expense and effort.

### *Regular Performance of Routine Maintenance Tasks*

The essence or core of any facility maintenance program is the regular, consistent performance of the actual maintenance tasks that the remainder of the program has identified, planned, and scheduled, and for which staff, equipment, and funding have been provided. The competent and consistent performance of these routine tasks is the single greatest factor in determining the success of the overall BMP inspection and maintenance program. These routine tasks normally include grass mowing and trimming, trash and debris removal, soil fertilization, and sediment removal. Experience has shown that the regular, frequent (e.g., monthly or less) performance of these tasks often requires less overall time and effort on an annual basis than if the tasks are performed only a few times a year.

In addition, a flexible and informed definition of "regular" should be adopted when scheduling routine maintenance tasks. For example, while it will be easier to schedule maintenance at a given BMP for the first week of every month, the actual performance of the work should instead be based on weather conditions and maintenance need. This is particularly true of turf grass, which may be damaged by a regularly scheduled mowing during dry or drought conditions. During wet conditions, attempts to perform maintenance tasks may result in rutting and other ground disturbances, causing more facility damage. The ability to perform "regular" maintenance tasks on a somewhat "irregular" basis is one of the greatest challenges of a comprehensive inspection and maintenance program.

### *Timely Performance of Emergency Maintenance Tasks*

Despite the best efforts of any inspection and maintenance program, emergency maintenance measures may be necessary at a structural BMP from time to time for a variety of causes, ranging from excessive rainfall to vandalism. As a result, the successful inspection and maintenance program must be ready to respond to this need in a timely and comprehensive manner. To do so, it is best to plan ahead for emergencies by developing an emergency response plan that identifies potential emergency problems and ways to address them. This may include the preparation of a list of typical repair materials, which then can be either stockpiled in house or quickly acquired through designated suppliers. The plan may also identify individuals and organizations that can provide technical input or services on short notice to assist in the emergency repair effort. Finally, a designated number of staff personnel should be available on a 24-hour basis to respond to maintenance emergencies.

### *Regular, Competent Inspections*

One of the keys to program efficiency and overall BMP safety is the performance of competent BMP inspection on a regular basis. In view of the increasingly complex nature of structural BMPs and the wide range of technical aspects inherent in each, the need for competent inspectors should be obvious. In fact, a team of inspectors may be necessary to adequately review the geotechnical, environmental performance, structural, hydraulic, and biological aspects of many BMPs. Inspections must be performed on a regular basis to identify problems and special maintenance needs quickly and efficiently. This allows repairs to be performed promptly without the need for major remedial or emergency action.

The frequency of inspections varies with the size and complexity of a given BMP. Regular inspections by qualified personnel may range from once a year for large facilities with high damage potential to every 2 to 5 years for smaller, less complex sites. Additional inspections should also be performed as appropriate following major rain storms and other extreme climatological events such as droughts, extreme snowfalls, or high winds. It should also be noted that the growing complexity and technical range of structural BMPs is expected to require more frequent inspections covering a wider range of BMP features.

Finally, the formal inspections described above should be supplemented by informal inspections conducted by maintenance personnel during each of their site visits. This further enhances the program's ability to quickly identify and respond to special maintenance needs before they can become costly emergencies. As noted above, such informal inspections require further training of maintenance personnel.

### *Performance Guarantees and Defaults*

In many BMP inspection and maintenance programs, the owners of the property on which the BMP is located are responsible for performing maintenance tasks. Such properties may range from single-family residences to major industrial or commercial complexes. Under such conditions, the governmental agency responsible for the overall success of the program must obtain some form of guarantee that the maintenance will in fact be performed. This guarantee is acquired through several steps. First, the property owner's responsibilities should be specified in a written agreement between the owner and the agency. This agreement should also grant the agency the right to enter the property and inspect the BMP to ensure that the stipulated maintenance is, in fact, being performed satisfactorily. In addition, the agreement should also provide a method by which the agency can perform both emergency and regular maintenance tasks in the event of default by the owner, including a provision to charge the owner for the cost. Finally, such an agreement should be binding on all future owners of the property to ensure continuity.

### *Accurate Recordkeeping*

In view of the large number of tasks, equipment, and materials that may be involved in a comprehensive BMP inspection and maintenance program, accurate records of the maintenance effort should be kept. This includes logs of time and manpower, records of material quantities and costs, and the type and frequency of the various maintenance tasks performed. In addition, accurate records should also be kept of any complaints received from community residents regarding the adequacy and/or frequency of the various maintenance tasks as well as all reports of potentially hazardous conditions. The time and expense of such recordkeeping, including the need for staff training in the proper procedures, can be quickly offset if the recorded information is used to improve scheduling, task performance, and purchasing practices. Additional details of such use is described below.

### *Productive Self-Evaluation and Interaction*

To achieve improved levels of efficiency, a BMP inspection and maintenance program should conduct regular reviews and self-evaluations. The availability of thorough program records is of great assistance in this effort. The program review should include input from all program personnel and should address such aspects as maintenance frequency, the sequence of facility visits, equipment suitability, staffing levels, and training needs. In addition, establishing a positive dialogue with stormwater regulators, designers, and contractors is highly desirable because all of these people are responsible for creating the structural BMPs that the inspection and maintenance program must ultimately (and forever) maintain. Studies and experience have shown that many of the problems encountered during BMP maintenance are actually the result of poor or misinformed regulations, designs, or construction efforts. Therefore, maintenance personnel need to identify such problems and be given a means to inform those responsible. Such interaction can be achieved through conferences and meetings with professional societies, industry groups, and governmental agencies and departments. Public input should also be sought through individual contacts (using the complaint records noted above) and community meetings.

## The Growing Need for BMP Performance Monitoring

More than just grass mowing, BMP inspection and maintenance represent a broad range of integrated technical activities. In fact, this can also be said for the entire field of modern stormwater management, which requires technical interaction between regulators, designers, contractors, maintenance personnel, and the public to truly achieve the goal of comprehensive runoff management. Unfortunately, due to the random and, at times, unpredictable behavior of storm events and the inherent complexity of the rainfall-runoff process, it is often difficult to determine how well our runoff goals are being met, regardless of the proficiency of design, construction, and maintenance efforts. For this reason, BMP performance monitoring should also be included in any stormwater management program.

By closely and accurately monitoring BMP performance through field monitoring, sampling, and laboratory analysis, BMP monitoring can enable us to better define the "problem" of runoff pollution and allow regulators and designers to gain a better understanding of both BMP function and performance. This information can be used more conclusively to identify those runoff goals and management functions that either can or cannot be realistically achieved by structural BMPs. This will further allow regulators and designers to improve those functions that are viable and to develop alternatives to those that are not, both through enhanced design standards and techniques and updated regulations. BMP performance monitoring can also provide information regarding construction and maintenance practices that may have an effect on facility performance, which can in turn lead to improved or new practices or equipment.

In overview, BMP performance monitoring can be seen as a means of achieving greater return on the time, materials, and property invested now and in the future in our stormwater management programs. And because these amounts are expected to grow considerably as we expand our programs to address more complex stormwater problems, the importance of such improved returns will certainly increase.

In addition, BMP performance monitoring can also be seen as a way to help ensure overall program credibility and achieve stronger community acceptance. In recent years, much attention has focused on the need to expand traditional stormwater management programs beyond structural measures to also include nonstructural measures in order to achieve more comprehensive results. To do so, we must achieve greater community involvement in our stormwater management efforts, both through lifestyle changes (involving a wide scope of activities, from pet care to car washing to home landscaping) and through participation in various nonstructural stormwater programs (ranging from household waste disposal to carpooling to resource preservation). With the real data obtained through BMP performance monitoring, it will be easier to convince the community of both the need for and the promise of stormwater management.

Such data will also lend greater credibility to our concerns over runoff pollution and will enable us to credibly demonstrate the value of both structural and nonstructural measures. Such credibility is vital if we are to expect the public to make the changes and sacrifices demanded by both the structural and nonstructural BMPs we now have or hope to implement in their communities (and even their backyards) in the future. Finally, BMP performance monitoring will help us to more closely monitor our progress and more quickly identify program problems and shortcomings. This will help us to develop and implement program modifications and improvements in a manner that will not threaten community acceptance. As noted earlier, we will not be able to rely on public support for nor participation in vital nonstructural stormwater programs if we are unable to create and maintain aesthetically pleasing structural BMPs. We can also expect similar results if we discover that those same BMPs simply do not work.

## Summary

- To achieve comprehensive success in our stormwater management efforts, it is vital that inspection, maintenance, and monitoring be considered as equal in importance to structural BMP planning, design, and maintenance.
- The neglect of BMP inspection and maintenance can actually result in worse environmental impacts to a community than the ones that the BMP was intended to prevent. This result can threaten the viability of the entire stormwater management program.
- BMP inspection and maintenance must be an official component of a comprehensive stormwater management program, with adequate staffing, equipment, and funds.
- Self-evaluation and interaction with regulators, designers, constructors, and members of the community are vital to reducing overall maintenance needs, efforts, and costs.
- BMP performance monitoring is increasingly important to the continued effectiveness and growth of stormwater management programs.

# *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*

**Rod Frederick**
**Office of Water, U.S. Environmental Protection Agency, Washington, DC**

## Abstract

This paper describes the technology-based management measures developed under Section 6217(g) of the Coastal Zone Act Reauthorization Amendments to control sources of nonpoint pollution in the coastal zone. The implementation of state coastal nonpoint source control programs, including the development of enforceable policies and mechanisms, is the subject of other papers. The management measures, and the various practices that can be implemented cost-effectively to achieve conformity with the management measures, are the subjects of this paper. The U.S. Environmental Protection Agency document *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1) contains most technical information available on the effectiveness of practices to control nonpoint source pollutants and the costs of these practices. Nonpoint sources addressed in the document include agriculture, forestry, urban areas, marinas, and hydromodification (dams, shorelines, and channels). Practices include nonstructural methods such as planning, pollution prevention, and source reduction alternatives in addition to structural methods such as detention ponds and composting facilities. A separate chapter of the document contains information on the protection and restoration of wetlands with nonpoint source pollution abatement functions and the use of vegetated treatment systems in nonpoint source control programs.

## Introduction

Section 6217 of the Coastal Zone Reauthorization Amendments of 1990 (CZARA) requires the development of coastal nonpoint source (NPS) control programs to protect and restore coastal waters. States with coastal zone management plans that the National Oceanic and Atmospheric Administration (NOAA) has already approved will develop the new NPS control programs by implementing management measures found in the U.S. Environmental Protection Agency (EPA) document *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1). The development process, including determination of program content, use of alternative management measures, and development of additional management measures to meet water quality standards, is described in a separate document (2) and is the subject of other papers. This paper focuses on the development of the management measures and their basis—the structural and nonstructural practices that can be used to cost-effectively control NPS pollution and achieve conformity with the management measures. The value of the management measures guidance as a comprehensive technical reference should not be underestimated because it was developed as guidance for coastal state programs; the management measures guidance contains detailed information on the cost and effectiveness of a wide variety of methodologies and technologies that have proven effective in controlling nonpoint sources of pollution in both coastal and noncoastal areas.

## Legislative Background

Congress enacted CZARA on November 5, 1990. A major focus of this law is the control of NPS pollution to avoid impacts on coastal waters. Congress showed concern in section 6202(a) that growing populations in the coastal zone are endangering wetlands and marine resources. Section 6217 addresses this concern by requiring that each state with an approved coastal zone management program develop a coastal NPS control program and submit it to NOAA and EPA for approval. The purpose of the coastal NPS control program is to develop and implement management measures for NPS pollution to restore and protect coastal waters, working closely with other state and local agencies. Simply stated, EPA develops the management measures and publishes them as guidance, and the states develop and implement programs in conformity with the management measures and program guidance.

Section 6217(g) of CZARA defines management measures as the best available controls that can be economically achieved to reduce pollutants from existing and new categories and classes of NPS pollution. The charge is clearly to develop technology-based controls to reduce pollution from nonpoint sources. In addition, Section 6217(b) of CZARA requires the implementation of additional water-quality-based management measures to protect impaired and critical coastal areas if implementation of the measures developed under Section 6217(g) is not effective at improving water quality.

## Guidance Development

To develop the guidance, EPA formed work groups composed of more than 250 people recognized as knowledgeable in the control of NPS pollution. The work groups corresponded to the six technical chapters of the management measures guidance and were cochaired by EPA staff and a combination of staff from NOAA, the U.S. Department of Agriculture (USDA) and the U.S. Forest Service. Other work group members included staff from state agencies, interstate agencies, research agencies, universities, and other federal agencies including the Bureau of Land Management, Fish and Wildlife Service, Army Corps of Engineers, Federal Highway Administration, National Park Service, and Geological Survey.

Work group members provided references, literature reviews, and advice as EPA worked with its own contractors and experts to pull together, analyze, and summarize information on management practices and their effectiveness. EPA released the proposed management measures guidance in May 1991. EPA and NOAA also published a proposed program implementation guidance in October 1991.

Input on the proposed management measures guidance was solicited from the public during a 7-month comment period. The major problems identified in the public comments on the technical chapters were a lack of cost information and a perceived "East Coast bias" in the practices identified. There were, however, many positive comments on the usefulness of the guidance as a compendium of structural and nonstructural control alternatives for NPS pollution in all areas of the country.

The final management measures guidance was released in January 1993. That document incorporated most suggested improvements and additional information received from the public comments, as well as 1) a more thorough literature review; 2) additional focus on regional differences in climate, weather, and geomorphology; 3) additional cost information; and 4) information on economic achievability. The final management measures guidance is more than twice the size of the May 1991 proposed guidance and, hopefully, twice as useful. There are more alternative practices, better descriptions, additional source reduction and pollution prevention programs, and examples of successful implementation of cost-effective practices under a variety of site conditions. Based on the favorable response to date on the final management measures guidance, the guidance is a valuable technical reference for identifying NPS problems and cost-effective solutions.

## Description of the Final Management Measures Guidance

### *Problem Identification*

Each chapter contains a discussion of NPS pollutants and problems as a rationale for the management measures and controls to be implemented as part of state coastal NPS control programs.

#### Agricultural Runoff

Coastal waters are affected by NPS pollution resulting from the erosion of crop land; from the manure and other wastes produced in confined animal facilities; from the application of nutrients, pesticides, and irrigation water to crop land; and from physical disturbances caused by livestock and equipment, particularly in and along streambanks.

#### Urban Runoff

Urbanization in the form of new development changes the natural hydrology of an area and increases runoff volumes, erosion, sediment loadings to surface waters, and loadings of sediment, nutrients, oxygen-demanding substances, pathogens, metals, hydrocarbons, and other pollutants. These changes and increases can impair water quality, alter habitats, close and destroy fisheries and shellfish beds, and close recreational areas such as beaches. Decreases in base flows caused by impervious areas can also adversely alter habitat and impair water quality. Existing urban activities such as the use of onsite disposal systems, improper disposal of household wastes, turf and lawn management, pets wastes, and road maintenance can also cause water quality problems.

#### Silvicultural (Forestry) Operations

Forestry operations can degrade water quality in water bodies receiving drainage from forest lands. Sediment concentrations can increase because of accelerated erosion; water temperatures can increase because of removal of the overstory riparian shade; slash and other debris can deplete dissolved oxygen; and organic and inorganic chemical concentrations can increase due to harvesting and the use of fertilizers and pesticides. Increased stream flow can also result from the removal of trees and vegetation.

### Marinas and Recreational Boating

Because marinas are located at the water's edge, a variety of nonpoint effects are associated with poor flushing of boat basins, spills from refueling areas, bilge pumping, and wastes produced by the cleaning and repair of boats.

### Hydromodification

Hydromodification activities have been separated into three categories:

- *Channelization and channel modification* frequently diminish the suitability of instream and streamside habitat for fish and wildlife, and alter instream patterns of water temperature and sediment transport. Hardening of banks, in particular, can increase the speed of movement of NPS pollutants from the upper reaches of watersheds into coastal waters.
- *Dams* can affect the hydraulic regime, the quality of surface waters, and the suitability of instream and streamside habitat for fish and wildlife.
- *Shoreline and streambank erosion* is a natural process that can have either beneficial or adverse impacts on surface water quality and on the creation and maintenance of coastal habitat. Eroded shoreline sediments help maintain beaches and replenish the substrate in tidal flats and wetlands. Excessively high sediment loads, however, can smother submerged aquatic vegetation, cover shellfish beds, fill in riffle pools, and contribute to increased levels of turbidity and nutrients.

### Wetlands and Vegetated Treatment Systems

Wetlands and riparian areas reduce NPS pollution by filtering pollutants—especially sediment, nitrogen, and phosphorus—from surface waters. Wetlands and riparian areas can also attenuate flows from higher-than-average storm events, thereby protecting receiving waters from peak flow hydraulic impacts such as channel scour, streambank erosion, and fluctuations in temperature. Degraded wetlands lose this important set of NPS control functions. Also, degradation of wetlands and riparian areas can cause these areas to become sources of nonpoint pollution because they will then deliver increased amounts of sediment, nutrients, and other pollutants to adjoining water bodies.

## *Management Measures and Practices*

The management measures are major subheadings within each chapter. The coastal NPS control programs that states are to develop must be in conformity with these measures. An applicability section for each measure contains information on the activities and locations to which each measure applies. A description section is included for each measure to illustrate goals and objectives and provide more detail on what the measures mean. The selection section provides the rationale used in selecting the management measure. Usually, selection is based on widespread use of a management practice or combination of practices that can be used to achieve the management measure. The economic achievability of the management measures was evaluated separately (3). If this evaluation affected the selection of a measure, the effect is described in the selection section.

Management practices are described in a separate section under each management measure for illustrative purposes. State programs do not have to specify or require the implementation of any of these management practices. EPA does expect, however, that one or a combination of these practices appropriate to local conditions can be used to achieve conformity with the management measures. For example, the management measure for runoff from new development calls for 80 percent reduction in the average annual total suspended solid (TSS) loadings. Several management practices such as sand filters or extended detention wet ponds can be used to achieve the required TSS removal. If local conditions are not appropriate for one of those practices, however, a combination of vegetated filter strips, grass swales, wet ponds, or constructed wetlands could also be used to achieve the measure. The costs and effectiveness of the management practices are usually included within the description of each practice or in a separate summary section at the end of each management measure chapter. An economic impacts study (3) was prepared based on representative practices and combinations of practices and their costs.

## *Management Measures by Chapter*

Presented below are brief synopses of the major management measures presented in each of the technical chapters. The discussion below is not comprehensive, and the management measures guidance should be consulted to establish the exact requirements and applicability of the management measures.

### Agriculture

- *Sediment and erosion control:* Rely on USDA's conservation management system to promote practices such as conservation tillage and strip-cropping.
- *Animal facilities (large units):* Contain runoff and animal waste in storage structures.
- *Animal facilities (small units):* Use less-stringent requirements for economic reasons.
- *Nutrient management:* Develop and implement comprehensive nutrient management plans that involve fertilizer application rates, timing, and use efficiency.

- *Pesticide management:* Evaluate the problem and site, use integrated pest management (IPM) where possible, and apply pesticides properly and safely.
- *Livestock grazing:* Protect sensitive areas through appropriate grazing management techniques (e.g., providing alternative water, salt, and shade sources away from sensitive areas and providing livestock crossing areas).
- *Irrigation:* Optimize water use and use chemigation safely.

**Forestry**

- *Preharvest planning:* Consider the timing, location, and design of harvest activities.
- *Streamside management areas (SMAs):* Establish SMAs to protect against soil disturbance and delivery of sediment and nutrients from upslope activities; retain canopy species to moderate water temperature.
- *Road construction/reconstruction and road management:* Reduce the generation and delivery of sediment.
- *Timber harvesting:* Protect waters during harvesting, yarding, and hauling.
- *Site preparation and forest regeneration:* Confine onsite potential NPS pollution and erosion resulting from these activities.
- *Management of fire, chemicals, and forested wetland areas:* Reduce NPS pollution of surface waters.
- *Revegetation of disturbed areas:* Prevent sedimentation from harvest units or road systems.

**Urban**

- *Runoff control for new development:* Reduce runoff levels of TSS by 80 percent, and maintain natural hydrology.
- *Watershed protection/site development:* Use comprehensive planning to protect areas that are ecologically sensitive, provide water quality benefits, or are prone to erosion.
- *Construction erosion/sediment and chemical control:* Reduce construction-related erosion, retain sediment onsite, and properly manage chemical use.
- *Runoff management for existing development:* Identify and implement runoff quality controls as appropriate and feasible.
- *New and operating onsite disposal systems (OSDSs):* Select, site, and operate OSDSs to reduce OSDS impacts on coastal waters.
- *Pollution prevention for urban areas:* Target and implement NPS reduction and public education programs.
- *Roads, highways, and bridges:* Site, construct, operate, and maintain roads, highways, and bridges properly.

**Marinas**

- *Marina siting and design:*
  - Allow for maximum flushing of the marina basin.
  - Perform water quality and habitat assessments to protect against adverse impacts on shellfish resources, wetlands, and submerged aquatic vegetation.
  - Control stormwater runoff (additional controls exist for hull maintenance areas).
- *Fueling station design:* Design to allow for ease of cleanup, and develop spill contingency plans.
- *Sewage facilities:* Ensure availability of pumpouts and pump stations, and develop maintenance procedures.
- *Operation and maintenance:* Establish marina operation and maintenance programs to control and to provide for proper disposal of solid waste, fish waste, liquid materials, petroleum products, and boat cleaning byproducts.
- *Public education:* Develop public education programs for marina users.

**Hydromodification**

- *Channelization and channel modification:* Evaluate effects of new projects on physical and chemical characteristics of surface waters and on instream and riparian habitats
- *Dams:* Control erosion/sediment and chemicals during and after construction; develop and implement an operation and maintenance plan to protect surface water quality and instream and riparian habitat.
- *Eroding shorelines and streambanks:* Stabilize streambanks and shorelines where erosion is a nonpoint problem; vegetative methods are strongly preferred over engineering structures where vegetation will be cost-effective. Protect streambanks and shorelines from erosion from the use of the shore and adjacent waters.

**Wetlands, Riparian Areas, and Vegetated Treatment Systems**

- *Protection:* Protect wetlands and riparian areas serving a NPS pollution abatement function to maintain water quality benefits and ensure that they do not become a source of nonpoint pollution.
- *Restoration:* Promote the restoration of damaged and destroyed wetlands and riparian systems where they will have a significant NPS pollution abatement function.

- *Vegetated treatment systems:* Promote the use of constructed wetlands and filter strips where they will serve a significant NPS pollution abatement function.

## Next Steps

### *1993*

NOAA and EPA began meeting with states and other interested parties to assist in program development and determine their needs for future technical assistance. Activities included:

- Regional workshops with state coastal zone management and NPS control agencies.
- Briefings of other federal agencies and interest groups (e.g., trade associations and environmental groups).
- Presentations at meetings of other interested parties (e.g., International Marina Institute, National Association of Conservation Districts, Water Environment Federation, and Coastal State Organization).

### *1994*

NOAA and EPA formulated and implemented a technical assistance program using information on needs obtained from state and local government, industry, trade organizations, and others. Elements of this program include:

- Publishing several guidance documents, including *State and Local Government Guide to Environmental Program Funding Alternatives* and *Developing Successful Runoff Control Programs for Urbanized Areas* (4, 5).
- Providing funds to help produce additional technical guidance, including *Urbanization and Water Quality, Watershed Protection Techniques,* and *Fundamentals of Urban Runoff Management* (6-8).
- Conducting workshops on such topics as stream restoration, NPS monitoring, and marina NPS controls.
- Developing educational curricula and sponsoring train-the-teacher programs on runoff NPS pollution.
- Developing an expert system for identifying and selecting agricultural NPS controls.

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# *Biotechnical Streambank Protection*

**Don Roseboom, Jon Rodsater, Long Duong, Tom Hill, Rich Offenback, Rick Johnson, John Beardsley, and Rob Hilsabeck**
**Illinois State Water Survey, Peoria, Illinois**

## Abstract

Streams in areas of intense residential and commercial development have high rates of surface water runoff, so bank erosion and downstream flooding become more common and severe. Throughout the greater Chicago area, this has resulted in destabilized streams lacking habitat for fish, wildlife, and people. The Illinois Environmental Protection Agency and the U.S. Environmental Protection Agency funded the urban stream restoration projects on Glen Crest Stream and the Waukegan River. During the spring and summer of 1992, stabilization sites were completed on Glen Crest Stream, in Glen Ellyn, and in Washington Park of the Waukegan Park District. The lunker technique was chosen for its low cost of installation and ability to resist the high-velocity runoff while increasing instream habitat for gamefish and the stream side habitat for the urban population. At Glen Ellyn, lunkers were constructed of recycled plastic lumber for increased longevity. Low-cost vegetative stabilization incorporated an initial matrix of grasses and willows, plus rooted stock of redosier dogwood near the water's edge, followed by appropriate riparian trees on the upper bank that the landowner chose. Both projects trained senior members and staff personnel of the park district and the city in the application of lunkers and vegetative stabilization.

## Introduction

This paper describes methods of biotechnical stabilization and instream habitat enhancement that have been field trialed in Illinois. These practices have been authorized and funded by the U.S. Fish and Wildlife Service, the Soil Conservation Service, the U.S. Environmental Protection Agency, and all Illinois state agencies responsible for stream modification permits. The following methods are described: willow post bank stabilization, lunker instream habitat enhancement with vegetative bank stabilization, and A-jack structural and vegetative bank stabilization (Figures 1, 2, and 3).

In rural Illinois areas, bank erosion is not addressed because of limited financial resources. In agricultural states, U.S. Army Corp of Engineers district offices receive many requests for assistance on bank erosion protection. Within recent years, the need for bank erosion control has been coupled with the need for environmental protection of the stream habitat and riparian areas for wildlife and fisheries. Keeping costs low while considering various environmental issues has made bank erosion control a difficult challenge for the Corps.

In Illinois, stream channel erosion increased when prairies were converted to rowcrop agriculture and residential development, thereby increasing surface water runoff rates. Man has become a dominant geomorphic factor in the watershed hydrology of both rural and urban watersheds. In most urban and agricultural areas, streams were channelized to move floodwaters away from valued lands, to maximize the size and uniformity of land holdings, even to decrease channel erosion (1). One result of increased water runoff rates and poorly designed channelization efforts has been massive bank erosion in the floodplains of Illinois streams.

Watershed studies by the Illinois State Water Survey have documented the channel erosion damages to floodplain fields and the consequent increased sediment yield. Channel erosion contributed 40 to 60 percent of the sediment yield in two monitored Illinois watersheds (2). Within these watersheds, increased runoff rates and stream channelizations caused the streambed to be downcut at first and then erode laterally to regain a meander shape (Figure 4). This process was hastened by channel incision into extremely unstable glacials and gravel deposits below an 8- to 20-ft layer of loess clays. The Crow Creek watershed study demonstrates both the bridge damages from channel incision and the field damages from bank erosion (3).

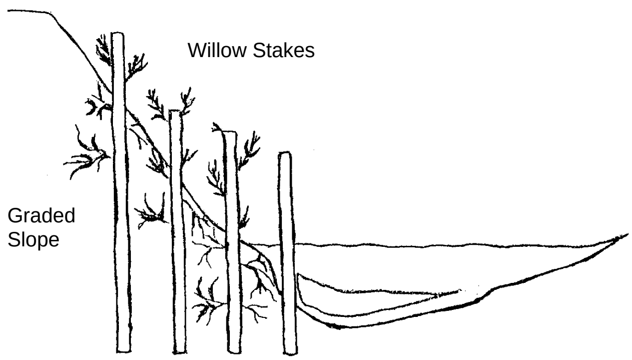


**Figure 1. Willow posts installed below depth of streambed scour.**

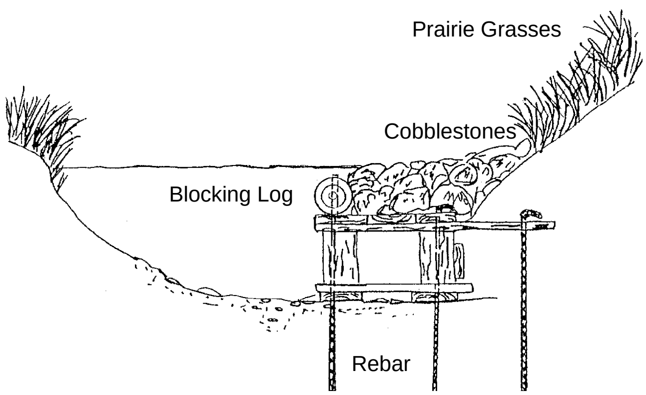


**Figure 2. Lunker with riprap below baseflow stage. Rebar is driven below bed scour depth.**

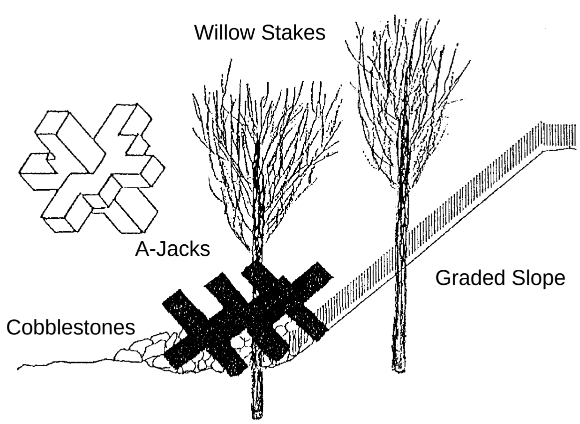


**Figure 3. A-jack bank structures.**

## Willow Post Bank Stabilization

The willow post method differs from most European bioengineering techniques (4, 5) in that individual willows are positioned vertically below the depth of channel scour. Most biotechnical bank stabilization techniques have used vegetation with a riprap mentality. Layers of horizontally bundled woody vegetation are entrenched in the bed and bank. This type of earth

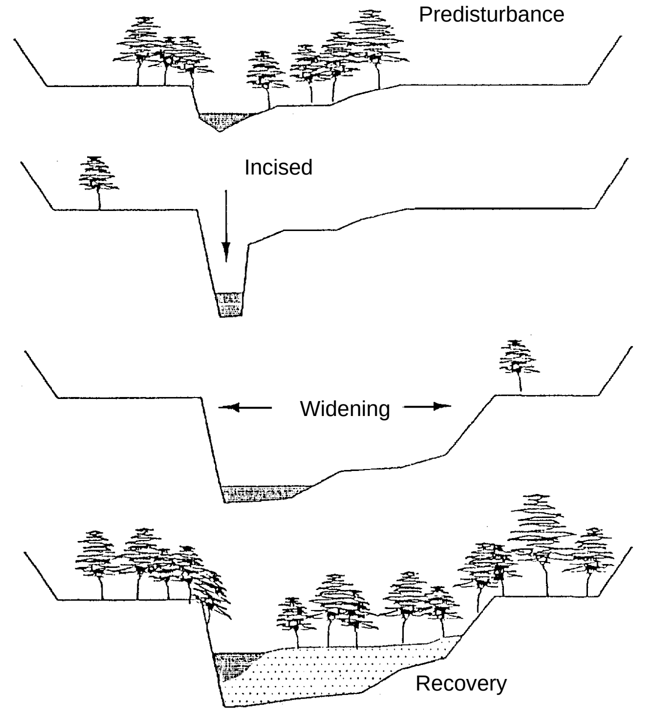


**Figure 4. Incision and recovery process. Vegetative bank stabilization can be applied during the widening phase.**

moving and hand labor often doubles installation costs and installation times.

Willows and most woody riparian vegetation do not naturally extend root systems very deeply below the water table. The posts are implanted much deeper than native seedlings would grow. Lateral root growth rapidly binds adjacent posts together in the bank soil. Lateral branch growth also interlocks adjacent posts to slow flow velocity near the bank.

The willow post method was mentioned by Scheichtl (4) as a method of ravine stabilization in Germany during the 1800s. Both the Corps of Engineers and the Soil Conservation Service used large willow poles in the 1930s (6, 7). In most cases, the posts or poles were laid as a layer along the sloped bank. York (8) placed willow posts in vertical holes to protect the base of levees in Arizona.

Willows are cut into 10- to 14-ft posts when the leaves have fallen and the tree is dormant. At this time, growth hormones and carbohydrates are stored in the root system and lower trunk. Dense stands of 4- to 6-year-old willows make the best harvesting areas. These stands are commonly found on the stream deltas in lakes or in old stream channel cutoffs. The willow posts are 4 to 6 in. in diameter and may be stored up to 1 month if kept wet.

The eroding streambank is shaped to a 1:1 slope with the spoil placed in a 6-in. deep layer along the top of the bank. In major erosion sites, post holes are formed in the bed and bank so that the end of the post is 2 ft below maximum streambed scour. The posts are placed 4 ft apart in rows up the streambank. The posts in one row are offset from the posts in adjacent rows.

While the steel ram and excavator is more efficient at depths of 6 ft in clay soils, a hydraulic auger and excavator unit forms deeper and longer lasting holes in stony or sand streambeds. Large stone layers of streambed material cause damage to the excavator when the steel ram is used. In fine sand layers, ram holes collapse before the post reaches the bottom of the holes. In highly fluid sands, even auger holes fill but the post can be pushed deeper with the bucket or boom. In streams with sand or gravel beds, the hydraulic auger places posts 9 to 11 ft deep in the bed. Almost all contractors in Illinois currently use an excavator and hydraulic auger unit.

In larger streams with noncohesive sand banks, large cedar trees are cabled to the willow posts along the toe of the bank. The cedars not only reduce bank scour while root systems are growing but also retain moisture during drought periods. In larger streams, such as Illinois's only designated scenic river, the Middle Fork, large rounded boulders were used as additional bank protection with the willow posts.

In Illinois, the contractor slopes 15-ft banks on a 1:1 grade for 80 cents per linear foot. Each post hole is augered 10 ft deep for $2.90. Each willow post costs $1 to $2. With a five-man crew at $10.00 per hour per man, bank sites are estimated to cost between $5 and $8 per linear foot.

## Bank Erosion Site Assessment

The following questions should be asked when determining the applicability of willow bank post stabilization:

1. Does sunlight fall directly on the eroding bank? (Willows must have sun.)
2. Is bedrock close to the surface? (Streambed material should be 4 ft deep; check with a tile probe.)
3. Are lenses of fine sand exposed in the eroding bank?
4. Is the stream channel stable upstream of the erosion site? (If the stream cuts behind the upper end of willow posts, the entire bank will erode.)
5. How deep is the stream along the eroding bank? (Willow posts must be 2 ft deeper than the deepest water or the posts will be undercut below the root zone. The length of the willow posts depends on the water depth. In sand or cobble streams, a hydraulic auger forms a deeper and more stable hole.)
6. How wide is the stream channel at the erosion sites compared with stable channels upstream and downstream? (If the channel is wider at the erosion site, vegetation will not choke the stream channel and cause other erosion problems.)
7. Do you have a source of large willows close to the site? (Your costs are small when the willows are close.)
8. Will the site be wet during dry summers? (Willow posts require a lot of water while the roots are regrowing; willow posts should only extend 1 to 2 ft aboveground in dry sites.)
9. Can you keep cattle away from the posts during the first summer? (Willows must be able to produce leaves for photosynthesis and regrowth.)
10. Have debris jams forced floodwater into the eroding bank? (Large debris jams must be removed according to guidelines established by the American Fisheries Society (9).)

The willow post method of bank stabilization is the lowest cost bank stabilization method that provides both wildlife and fisheries benefits. This method has received widespread support by both the agricultural and environmental communities: Farm Bureau, soil and water conservation districts, American Fisheries Society, and Nature Conservancy. The willows serve only as a pioneer plant on the disturbed soils. Succession to wooded or grass banks is speeded by additional trees or grass plantings with active site management if the landowner desires.

## Lunker Instream Habitat Structures

Lunkers are constructed of 2-in. oak planks (10). The planks form upper and bottom layers so that the interior is open to water flow at both ends and on the stream side of the structure (Figure 2). A series of lunkers are placed along the base of the eroding bank. When necessary, the lunkers are placed into an excavated trench, especially on the upper and lower ends of the sites. Each lunker is held with nine lengths of rebar, which are driven 5 ft into the streambed. In the Illinois adaptation, riprap was placed only on lunkers behind the blocking log.

In rural areas and in state parks, the bank above the lunkers was stabilized with willow posts. The bank was steeply sloped to keep the lunkers scoured (11) and to prevent silt deposition in the lunkers. In Court Creek, the upper bank was seeded with prairie grasses. During the second year, the posts were cut down so that only a narrow fringe of willow grew along the water's edge. By the third year, with active burn management, the prairie grasses had become established.

At Franklin Creek State Park, the banks were seeded with cool season grasses because the erosion site was located beside the equestrian corral. Once again, the willow posts were to be cut during the second year. A large population of protected beavers sped up the postcutting schedule. A spray of Ropel, an unpleasant-tasting liquid, mixed with a tackifer (to decrease water solubility) gave protection until the grasses became established. When Ropel applications were discontinued, the large posts were quickly cut down. Even with heavy browsing, however, the willow stubs regrew branches because the root systems were not damaged.

While the cool season grasses became established more quickly than the prairie grasses, the root systems of cool season grasses are shallow and therefore more susceptible to scour during high velocity flows. While damages have been minor after 4 years, two 9 $ft^2$ areas were seeded with grasses and 18-in. willow cuttings in April 1993. Adult smallmouth bass populations increased over 50 percent. Of more importance to stream bass populations, the yearling bass survival increased 300 percent at the lunker site (12).

Costs of lunker installation were $25 to $35 per linear foot, with prairie grass seeding and maintenance accounting for higher costs at the Court Creek site. Labor was 45 percent of costs, contractual equipment was 30 percent, and materials were 25 percent. A 300-ft site is estimated to cost $8,000 to $10,000.

## Urban Lunkers

In northeastern Illinois near Chicago, urban streams respond quickly to rainfall events so that floods are extremely erosive. Damage to homes and the higher cost of lands allow more intensive stream management. Often this has led to concrete or heavily riprapped stream channels with acute environmental damages. While necessary in some urban settings, the value of residential homes and parks can be increased if stream channel stabilization can be made more environmentally sensitive. In the smaller stream, the lunkers were constructed from recycled plastic lumber so that lunkers would not dry rot during lowflow drought periods. In larger stream segments, deeper pools allowed the use of wooden lunkers.

In urban streams, the higher cost of materials, the higher cost of contractual equipment as excavators, and the very high cost of landscape repairs to private lawns substantially increase the cost of lunker installation. The lunker installations are $45 to $55 per linear foot of bank.

Summer scheduling of stream restoration required the use of rooted and therefore smaller willow saplings. Additional rooted stock as redosier dogwood played a greater role in riparian revegetation of urban sites. Tree corridors were preserved as sound barriers to traffic noises and visual privacy barriers between homes. The resulting shade, however, denied the use of willows in some areas. In these shaded areas, redosier dogwood were planted with very good survival.

These urban sites were only 1 year old at the time this paper was presented, but the Chicago area had just undergone an extremely wet fall and spring. Two fall floods and three spring floods did not damage the urban lunkers sites.

## A-Jack Structures With Willow and Dogwood Bank Revegetation

A-jacks look like small versions of the World War II tank traps (see Figure 3). The A-jacks can be placed so that each A-jack will interlock within each row and with A-jacks in adjacent rows. The lowest rows of A-jacks are trenched along the base of the eroding bank, with the excavated sediment placed along the top of the bank. In the Glen Crest Stream and the Waukegan River, 2-ft diameter A-jacks were used.

Fibredam, a geotechnical fabric that locks the curled wood fibers in excelsior blankets, was placed between the rows of A-jacks and the bank soils to reduce soil movement through the A-jacks. Fibredam is easily torn apart and molded into crevices between A-jacks.

Willow cuttings were driven into the streambed between A-jacks and behind the last interior rows of A-jacks. The fluid sediment was placed on the rows and allowed to fill the interior spaces. The vertical streambank was then sloped over the A-jacks.

This structure ran $45 to $50 per linear foot of bank when composed of two base rows and one upper row. The cost of materials was $25 per foot. Ease of handling and suitability for transport by small marsh vehicles are advantages of this system. Each A-jack is composed of two halves that lie flat on pallets during transport. A-jacks are assembled at the bank site.

When the willows and dogwood are fully grown, root systems lock the entire structure together while giving a natural appearance to the streambank. Small stone is added to A-jack rows near the waterline to give a more natural appearance.

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# The Use of Wetlands for Stormwater Pollution Control

**Eric W. Strecker**
**Woodward-Clyde Consultants, Portland, Oregon**

## Abstract

This paper presents the results of a literature review that summarizes the current state of knowledge regarding the use of wetlands for stormwater pollution control. The paper reviews the primary removal mechanisms in wetlands, including sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. The results from 26 wetlands are reviewed and contrasted regarding their ability to remove pollutants from stormwater. The systems range from salt marshes to high-elevation riverine wetlands. The study sites are reviewed in relation to the type of wetlands system, including design features and upstream watershed characteristics. The wetlands receive stormwater from different land uses, including residential, commercial, highway, golf courses, and open. The observed pollutant removal efficiencies are quite variable but generally show good removals of phosphorus (median of 46 percent average removal) and the heavy metals cadmium, copper, lead, and zinc (median of 70, 40, 83, and 42 percent average removal, respectively) from stormwater. Constructed wetlands generally perform better and with greater consistency. In general, larger wetlands perform better than their watershed areas as well. Nevertheless, some carefully planned constructed systems with a small area performed quite well compared with their watershed areas. Because there is little information on noted impacts to biota, these are just briefly reviewed. Finally, the paper suggests collecting additional information in new studies. This would make comparisons among different sites more useful in assessing the factors that affect the abilities of constructed wetlands to remove pollutants from stormwater.

## Introduction

Constructed wetlands are receiving increasing attention as attractive systems for removing pollutants from stormwater runoff. Other potential benefits that such systems provide include flood control and habitat. Wetlands have long been used for the treatment of wastewaters from municipal, industrial, and agricultural sources (1). The U.S. Environmental Protection Agency (EPA) encourages the use of constructed wetlands for water pollution control through the innovative and alternative technology provisions of the construction grants program (2).

The purpose of this paper is to assist EPA, state, and local technical personnel in assessing the capabilities and limitations of using wetlands as a control measure to reduce the environmental impacts of stormwater pollution on downstream water bodies. The paper summarizes a report prepared for EPA by Strecker et al. (3) that reviewed published literature and documented reports on aspects of stormwater wetland design, operation, and performance. An appendix that accompanied the published report included a one- to six-page summary of each pertinent study reviewed for the report. The summaries covered influent and effluent water quality, the effectiveness of the system, flows and volumes, wetland and watershed areas, and the biological characteristics of the system.

Table 1 presents a list of selected reports with which researchers have documented the ability of wetland systems to remove pollutants from stormwater. The table includes some general characteristics of the wetland systems. Figure 1 shows the wetlands' geographic locations. The wetlands differed widely in location and wetland type (e.g., Florida's southern swamplands, Minnesota's northern peatlands, California's brackish marshlands, and Puget Sound's palustrine wetlands). Each of these locations differs in climate, vegetation, and soil types.

## Wetland Stormwater Pollutant Removal Mechanisms

Wetlands can combine various actions to remove pollutants from stormwater:

- Incorporation into or attachment to wetland sediments or biota.
- Degradation.

**Table 1. Literature Researched To Investigate Performance Characteristics of Wetlands**

| Study/ Reference | Year of Publication | Location | Name/I.D. | Detention Pond/Wetland | Constructed/ Natural | Wetland Classification |
|---|---|---|---|---|---|---|
| Martin and Smoot (4) | 1986 | Orange County, FL | Orange County Treatment System | Detention pond and wetland | Constructed | Hardwood cypress dome |
| Harper et al. (5) | 1986 | FL | Hidden Lake | Wetland | Natural | Hardwood swampland |
| Reddy et al. (6) | 1982 | Orange County, FL | Lake Apopka | Wetland | Constructed | Cattail marsh |
| Blackburn et al. (7) | 1986 | Palm Beach, FL | Palm Beach PGA Treatment System | Wetland | Constructed and natural | Southern marshland |
| Esry and Cairns (8) | 1988 | Tallahassee, FL | Jackson Lake | Detention pond and wetland | Constructed | Southern marshland |
| Brown, R. (9) | 1985 | Twin Cities Metro Area, MN | Twin Cities Metro | Wetlands | Natural and constructed | Northern peatland |
| Wotzka and Oberts (10) | 1988 | Roseville, MN | McCarrons Treatment System | Detention pond and wetland | Constructed | Cattail marsh |
| Hickok et al. (11) | 1977 | MN | Wayzata | Wetland | Natural | Northern peatland |
| Barten (12) | 1987 | Waseca, MN | Clear Lake | Wetland | Constructed | Cattail marsh |
| Meiorin (13) | 1986 | Fremont, CA | DUST Marsh | Wetland | Constructed | Brackish marsh |
| Morris et al. (14) | 1981 | Tahoe Basin, CA | Tahoe Basin Meadowland | Wetland | Natural | High elevation riverine |
| Scherger and Davis (15) | 1982 | Ann Arbor, MI | Pittsfield-Ann Arbor Swift Run | Detention pond and wetland | Constructed and natural | Northern peatland |
| ABAG (16) | 1979 | Palo Alto, CA | Palo Alto Marsh | Wetland | Natural | Brackish marsh |
| Jolly (17) | 1990 | St. Agatha, ME | Long Lake Wetland-Pond Treatment System | Detention pond and wetland | Constructed | Cattail marsh |
| Oberts et al. (18) | 1989 | Ramsey-Washington Metro Area, MN | Tanners Lake, McKnight Lake, Lake Ridge, and Carver Ravine | Detention pond and wetland | Constructed | Cattail marsh |
| Reinelt and Horner (19, 20) | 1990 | King County, WA | B3I and PC12 | Wetland | Natural | Palustrine |
| Rushton and Dye (21) | 1990 | Tampa, FL | Tampa Office Pond | Wetland | Constructed | Cattail marsh |
| Hey and Barrett (22) | 1991 | Wadsworth, IL | Des Plaines River Wetland Demonstration Project | Wetland | Constructed | Freshwater riverine |


**Figure 1. Location of wetlands researched for their ability to treat stormwater runoff.**

- Export of pollutants to the atmosphere or ground water.

Both physical and chemical pollutant removal mechanisms probably occur in wetlands. These mechanisms include sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. Because of the many interactions between the physical, chemical, and biological processes in wetlands, these mechanisms are generally not independent. Sedimentation is usually the most dominant removal mechanism. The large variation in wetland characteristics (e.g., hydrology, biota) may cause the dominant removal mechanisms to vary from wetland to wetland. Variations in wetland characteristics can also help explain why wetlands differ so widely in their pollutant removal efficiencies. Following is a brief description of the principal removal mechanisms.

## *Sedimentation*

Sedimentation is a solid-liquid separation process using gravitational settling to remove suspended solids. It is considered the predominant mechanism for the removal of many pollutants from the water column in wetland and other flow detention systems. Sedimentation of suspended material, along with pollutants that are highly adsorbed, has been documented as the primary removal mechanism in wetlands by many study authors, including Martin and Smoot (4) and Oberts (23). The most significant factors affecting settling of suspended material pertain to the hydraulic characteristics of the wetland system, including the detention time, inlet-outlet conditions, turbulence, and depth. The opposite of sedimentation is flotation. Floatable pollutants such as oil and grease, litter, and other pollutants can accumulate in the surface microlayer. These pollutants can be removed by adsorption.

## *Adsorption*

Adsorption of pollutants onto the surfaces of suspended particulates, sediments, vegetation, and organic matter is a principal mechanism for removing dissolved or floatable pollutants. The literature suggests that these processes remove pollutants such as phosphorus, dissolved metals, and other adsorbents (including colloidal pollutants) (5, 11, 16). Adsorption occurs through three main processes:

- Electrostatic attractions.
- Physical attractions (e.g., Van der Waals forces and hydrogen bonding).
- Reactions.

The rates by which these processes occur are thought to be inversely related to the particle size and directly related to the organic content of the particles in the wetland soils (5). Increasing the contact of stormwater with the underlying soils and organic matter can enhance adsorption processes. In addition, high residence times, shallow water depths, and even distribution of influent enhance the interactions of water with soil and plant substances, thereby increasing the adsorption potential.

### *Precipitation and Dissolution*

Many ionic species (e.g., metals) dissolve or precipitate in response to changes in the solution chemistry of the wetland environment. Metals such as cadmium, copper, lead, mercury, silver, and zinc can form insoluble sulfides under the reduced conditions commonly found in wetlands (24). Decaying organic matter releases fulvic and humic acids that can form complexes with metal ions. In addition, decreased pH can promote the dissolution of metals, thereby making them available for bonding to inorganic and organic molecules (25).

### *Filtration*

Filtration occurs in most wetlands simply because vegetation acts like a sieve to remove pollutants and sediments from the water column. Dense vegetation can be very effective at removing floatables (including oil and grease) and litter from stormwater. Filtration can also take place in the soil matrix when infiltration occurs. Brown (9) and Wotzka and Oberts (10) also noted that increased density of vegetation slows the velocity and wave action, thereby allowing increased settling of suspended material.

### *Biochemical Interactions*

Vegetative systems possess a variety of biochemical interaction processes that can remove nutrients and other material from the water column. In general, these processes are:

- High plant productivity and associated nutrient uptake
- Decomposition of organic matter
- Adsorption
- Bacterially aerobic or anaerobic mediated processes

Through interactions with the soil, water, and air, plants can increase the assimilation of pollutants within a wetland system. Plants provide surfaces for bacterial growth and adsorption, filtration, nutrient assimilation, and the uptake of heavy metals (26).

### *Volatilization and Aerosol Formation*

Volatilization (or evaporation) can remove volatile pollutants from wetlands. Air and water temperature, wind speed, subsurface agitation, and surface films can affect the rate of volatilization. Surface films may act as a barrier for the volatilization of some substances. Alternatively, evaporation may be a key mechanism for exporting substances such as chlorinated hydrocarbons or oils, which are often found in the surface films of water bodies receiving urban stormwater runoff (26). Aerosol formation may play only a minor role in removing pollutants in wetlands and occurs only during strong winds (26).

### *Infiltration*

For wetlands with underlying permeable soils, infiltration can remove pollutants. Stormwater percolates through the soil, eventually reaching ground water. Passage through the soil matrix can provide physical, chemical, and biological treatment depending on the matrix thickness, particle size, degree of saturation, and organic content. Infiltration is also dependent on the groundwater level at a site. In some instances, seasonal fluctuations in ground-water levels may cause some wetlands to discharge ground water during part of the year and recharge to ground water during other times of the year. The potential of pollutants to migrate to ground water depends highly on the type of pollutant, the soil type and properties, the hydrology, and the characteristics of the aquifer. Contamination of unconfined aquifers by stormwater is likely to be more significant from upland infiltration than from recharge through wetlands because of the high filtering action of typical wetland soils (27).

## Wetland Stormwater Pollutant Removal Efficiencies

Only a limited number of studies have investigated the effectiveness of wetlands to treat stormwater runoff (Figure 1), and those have primarily focused on a few geographical locations (e.g., Florida, Minnesota, and California). The studies that this paper summarizes represent a wide diversity of wetland types, ranging from southern cypress swamplands and northern peatlands to brackish marshlands and high-elevation meadowlands. This section presents a discussion of wetland stormwater pollutant removal efficiencies found in the literature.

Table 2 summarizes reported removal efficiencies for total suspended solids (TSS) and selected nutrients and metals. The broad ranges of pollutant removal efficiencies were not surprising because wetlands vary in their hydraulic conditions, climate, and vegetation, and because the studies employed various monitoring and reporting procedures. Figure 2 presents histograms of pollutant removal efficiencies reported for TSS, total phosphorus (TP), ammonia ($NH_3$), and lead (Pb).

**Table 2. Average Removal Efficiencies for Total Suspended Solids and Nutrients in Wetlands Reported in the Literature**

| | | | Pollutant Removal Efficiency (Percent)[a] | | | | | | | Lead | | Zinc | | Copper | | Chromium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **System Name** | **System Type** | **TSS** | **$NH_3$** | **$NO_3$** | **TP** | **Dis. P** | **COD** | **BOD** | **Total** | **Dissolved** | **Total** | **Dissolved** | **Total** | **Dissolved** | **Total** | **Dissolved** |
| Martin and Smoot (4) | Orange County Treatment System | Detention pond* | 65 | 60 | -17 | 33 | 76 | 7 | | 39 | 29 | 15 | -17 | | | | |
| | | Wetland* | 66 | 54 | 40 | 17 | -30 | 18 | | 73 | 54 | 56 | 75 | | | | |
| | | Entire system | 89 | 61 | 9 | 43 | 21 | 17 | | 83 | 70 | 70 | 65 | | | | |
| Harper et al. (5) | Hidden Lake | Wetland | 83 | 62 | 80 | 7 | | | 81 | 55 | 56 | 41 | 57 | 40 | 29 | 73 | 75 |
| Reddy et al. (6) | Lake Apopka | Reservoirs | | 57.5 | 68.1 | 60.9 | 75.1 | | | | | | | | | | |
| | | Flooded fields | | 51.9 | 64.2 | 7.3 | 16.7 | | | | | | | | | | |
| Blackburn et al. (7) | Palm Beach PGA Treatment System | System | 50 | 17 | 33 | 62 | | | 35 | | | | | | | | |
| Esry and Cairns (8) | Jackson Lake | System | 96 | 37 | 70 | 90 | 78 | | | | | | | | | | |
| Brown (9) | Fish Lake | Wetland/pond | 95 | 0 | | 37 | 28 | | | | | | | | | | |
| | Lake Elmo | Wetland | 88 | 50 | | 27 | 25 | | | | | | | | | | |
| | Lake Riley | Wetland | -20 | 25 | | -43 | -30 | | | | | | | | | | |
| | Spring Lake | Wetland | -300 | -86 | | -7 | -10 | | | | | | | | | | |
| Wotzka and Oberts (10) | McCarrons Wetland Treatment System | Detention pond* | 91 | | 60 | 78 | 57 | 90 | | 85 | | | | | | | |
| | | Wetland* | 87 | | 22 | 36 | 25 | 79 | | 68 | | | | | | | |
| | | System | 94 | | 63 | 78 | 53 | 93 | | 90 | | | | | | | |
| Hickock et al. (11) | Wayzata Wetland | Wetland | 94 | -44 | | 78 | | | | 94 | | 82 | | 80 | | | |
| Barten (12) | Clear Lake | Wetland | 76 | 55 | | 54 | 40 | | | | | | | | | | |
| Meiorin (13) | DUST Marsh | | | | | | | | | | | | | | | | |
| | Basin A | Wetland* | 63 | -8 | 32 | 46 | | | -25 | 30 | | 42 | | -20 | | 55 | |
| | Basin B | Wetland* | 40 | -5 | 2 | -4 | | | -46 | 27 | | 24 | | -60 | | 47 | |
| | Basin C | Wetland | 51 | 18 | 12 | 36 | | | -18 | 83 | | -29 | | 17 | | 13 | |
| | System | Wetland* | 76 | 16 | 29 | 58 | | | -57 | 88 | | 42 | | -19 | | 66 | |
| Morris et al. (14) | Angora Creek | Wetland | 54 | 20 | 50 | 5 | | | | | | | | | | | |
| | Tallac Creek | Wetland | 36 | 33 | 35 | -120 | | | | | | | | | | | |

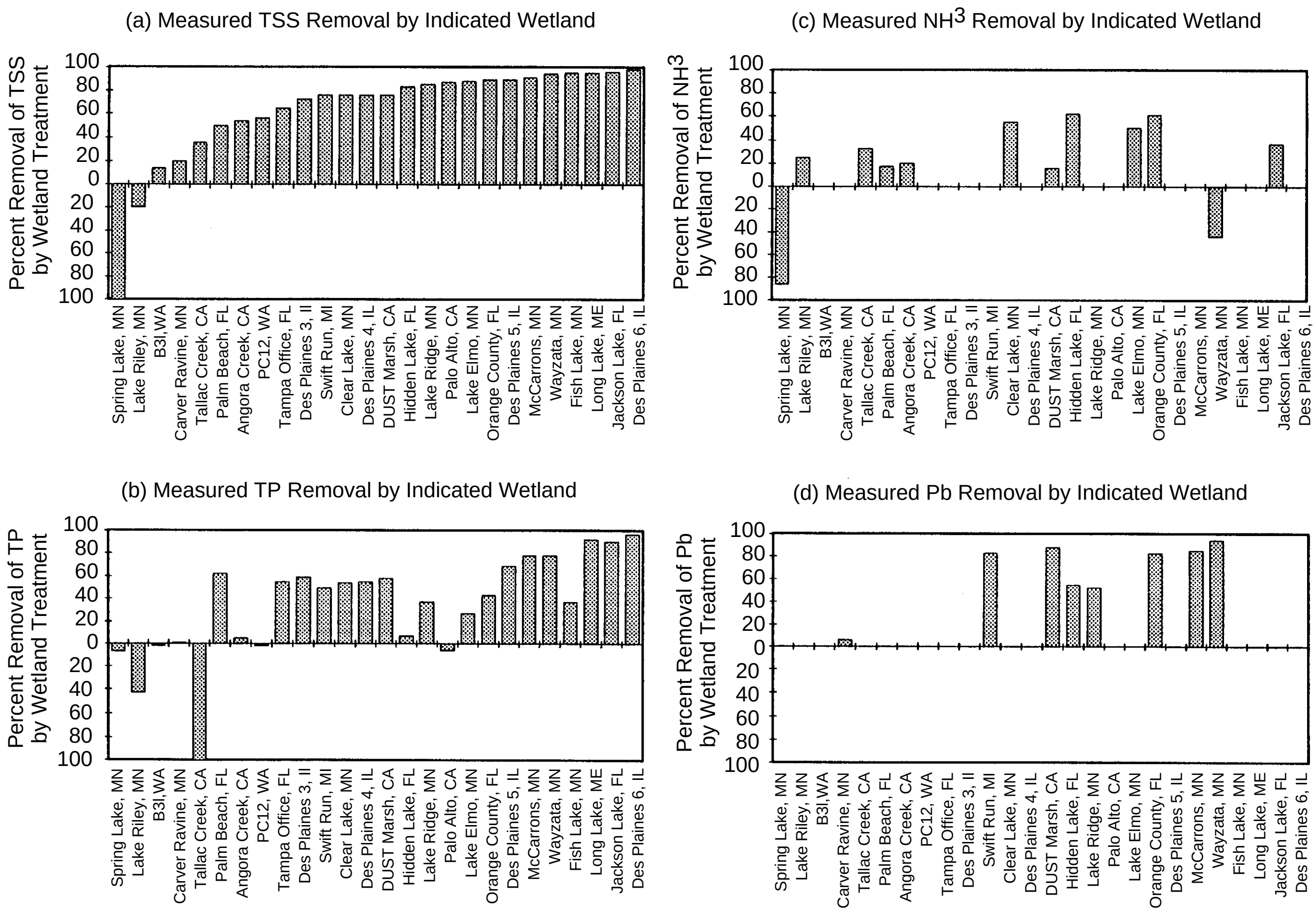
Table 2. Average Removal Efficiencies for Total Suspended Solids and Nutrients in Wetlands Reported in the Literature (continued)

| | | | Pollutant Removal Efficiency (Percent)[a] | | | | | | | Lead | | Zinc | | Copper | | Chromium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Study | System Name | System Type | TSS | $NH_3$ | $NO_3$ | TP | Dis. P | COD | BOD | Total | Dissolved | Total | Dissolved | Total | Dissolved | Total | Dissolved |
| Scherger and Davis (15) | Pittsfield-Ann Arbor Swift Run | Detention pond* | 39 | | | 23 | | | | 61 | | | | | | | |
| | | Wetland | 76 | | | 49 | | | | 83 | | | | | | | |
| ABAG (16) | Palo Alto Marsh | Wetland | 87 | | | -6 | | | 54 | | | | | | | | |
| Jolly (17) | Long Lake Wetland-Pond Treatment System | Entire system | 95 | | | 92 | | | | | | | | | | | |
| Oberts et al. (18) | Tanners Lake | Detention pond* | 63 | | 1 | 7 | -14 | | | 59 | | | | | | | |
| | McKnight Lake | Detention ponds* | 85 | | 11 | 34 | 12 | | | 63 | | | | | | | |
| | Lake Ridge | Wetland | 85 | | 17 | 37 | 8 | | | 52 | | | | | | | |
| | Carver Ravine | Wetland-pond system | 20 | | 9 | 1 | 1 | | | 6 | | | | | | | |
| Reinelt and Horner (19, 20) | B3I | Wetland | 14 | | 4 | -2 | | | | | | | | | | | |
| | PC12 | Wetland | 56 | | 20 | -2 | | | | | | | | | | | |
| Rushton and Dye (21) | Tampa Office Pond | Wetland | 64 | | | 55 | | | | | | 34 | | | | | |
| Hey and Barrett (22) | Des Plaines River Wetland | | | | | | | | | | | | | | | | |
| | EWA 3 | Wetland | 72 | | 70 | 59 | | | | | | | | | | | |
| | EWA 4 | Wetland | 76 | | 42 | 55 | | | | | | | | | | | |
| | EWA 5 | Wetland | 89 | | 70 | 69 | | | | | | | | | | | |
| | EWA 6 | Wetland | 98 | | 95 | 97 | | | | | | | | | | | |
| Median pollutant efficiency for wetland systems (without *) | | | 76 | 33 | 46 | 46 | 23 | 55 | 45 | 83 | 63 | 42 | 61 | 40 | 29 | 70 | 75 |

[a]Negative removal efficiencies indicate net export in pollutant loads.

COD = chemical oxygen demand

BOD = biochemical oxygen demand




Note: No bar indicates that the removal estimates were not reported for this parameter at the indicated wetland.

**Figure 2. Pollutant removal rates for a) TSS, b) TP, c) $NH_3$, and d) Pb.**

Despite the variability observed in pollutant removal efficiencies, some similarities exist among the wetlands. The following observations can be made:

- Suspended solids and total lead (TPb), followed by total zinc and chromium, show the greatest consistency with pollutant removal efficiencies.
- Suspended solid removal efficiencies tend to be more consistent and larger in constructed wetlands than in natural systems. This is likely due to the design and management of the constructed systems.
- In some cases, concentrations of dissolved Pb, zinc, and copper appear to be reduced significantly.
- Nutrient removal efficiencies vary widely among wetlands. The variations appear to be a function of the season, vegetation type, and wetland systems management methods.
- Total phosphorus and nitrate show the greatest consistency for nutrient removal efficiencies. Total phosphorus removal efficiencies tend to be more variable for the natural wetlands and less variable for detention basins and constructed wetlands.

## Probable Causes of Variations and Dissimilarities of Reported Wetland Pollutant Removal Effectiveness

In addition to the efficiencies that the authors tabulated, several reports presented conclusions to help explain the effectiveness of wetland treatment and variations. Hydrology is reportedly the most critical parameter influencing wetland performance. Variations in local hydrology, detention times, rates of runoff, water level fluctuations, and seasonality all reportedly affect the function of wetlands and thus their effectiveness at removing pollutants (25). Table 3 presents geographic, hydrologic, and hydraulic characteristics for each of the wetlands reviewed.

The size and volume of a wetland system can greatly affect both the actual removal efficiencies and the ability to estimate these efficiencies. EPA (26) reported difficulties in estimating pollutant removal efficiencies due to the volume of the wetland basin. The volume of the Demonstration Urban Stormwater Treatment (DUST) marsh is large enough that the treatment cycle spans several storms; therefore, no one storm provided a complete picture of pollutant efficiencies. The DUST marsh accu-

**Table 3. Wetland Geographic and Hydraulic Characteristics**

| Study | System Name | Watershed Land Use | % Land Use | System Type | Constructed/ Natural | Wetland Size (acres) | Watershed Size (acres) | Wetland/ Watershed Ratio | Average Flows ($ft^3$/sec) | Basin Volume (acre-ft) | Detention Time (hr) | Depth (ft) | Inlet Condition | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Martin and Smoot (4) | Orange County Treatment System | Residential | 33 | Detention pond | Constructed | 0.2 | 41.6 | 0.5% | 2.5 | 1.2-1.9 | 7.5 | 8-11 | Discrete | a |
| | | Highway | 27 | Wetland | Constructed | 0.78 | NA | 1.9% | NA | 0.5-2.8 | 8 | 0-5 | Discrete | |
| | | Forest | 40 | System | Constructed | 0.98 | | 2.4% | | | | | | |
| Harper et al. (5) | Hidden Lake | Residential | NA | Wetland | Natural | 2.5 | 55.2 | 4.5% | 0.22 | NA | NA | NA | Diffuse | b |
| Reddy et al. (6) | Lake Apopka | Agriculture | 100 | Reservoirs | Constructed | 0.9 | NA | NA | 0.56 | 2.6 | 9.4 days | 3.3 | Diffuse | c |
| | | | | Flooded fields | Constructed | 0.9 | NA | NA | 0.23 | 0.6 | 4.8 days | 0.7 | Diffuse | |
| Blackburne et al. (7) | Palm Beach PGA Treatment System | Residential | NA | Wetland | Constructed | 89 | 2,350 | 3.8% | NA | NA | NA | NA | Diffuse | c |
| | | Golf course | NA | Wetland | Constructed + natural | 296 | 2,350 | 12.6% | NA | NA | NA | NA | Diffuse | d |
| Esry and Cairns (8) | Jackson Lake | Urban | NA | Detention pond | Constructed | 20 | 2,230 | 0.9% | NA | 150 | NA | 7.5 | Diffuse | c |
| | | | NA | Wetland | Constructed | 9 | 2,230 | 0.4% | NA | 13.5 | NA | 1.5 | Diffuse | |
| Brown (9) | Fish Lake | Residential | 30 | Wetland | Natural | 16 | 700 | 2.3% | 0.001–0.01 | 64 | NA | 4 | Discrete | e |
| | | Commercial | 5 | | | | | | | | | | | |
| | | Agricultural | 12 | | | | | | | | | | | f |
| | | Open | 53 | | | | | | | | | | | |
| | Lake Elmo | Residential | 12 | Wetland | Natural | 225 | 2,060 | 10.9% | 0.001-0.65 | 900 | NA | 4 | Discrete | g |
| | | Commercial | 1 | | | | | | | | | | | |
| | | Agricultural | 34 | | | | | | | | | | | |
| | | Open | 53 | | | | | | | | | | | |
| | Lake Riley | Residential | 13 | Wetland | Natural | 77 | 2,475 | 3.1% | 0.004-1.35 | 231 | NA | 3 | Discrete | |
| | | Commercial | 2 | | | | | | | | | | | |
| | | Agricultural | 30 | | | | | | | | | | | |
| | | Open | 55 | | | | | | | | | | | |
| | Spring Lake | Residential | 5 | Wetland | Constructed | 64 | 5,570 | 1.1% | 0.008-4 | 256 | NA | 4 | Discrete | |
| | | Commercial | 1 | | | | | | | | | | | |
| | | Agricultural | 57 | | | | | | | | | | | |
| | | Open | 37 | | | | | | | | | | | |

**Table 3. Wetland Geographic and Hydraulic Characteristics (continued)**

| Study | System Name | Watershed Land Use | % Land Use | System Type | Constructed/ Natural | Wetland Size (acres) | Watershed Size (acres) | Wetland/ Watershed Ratio | Average Flows ($ft^3/sec$) | Basin Volume (acre-ft) | Detention Time (hr) | Depth (ft) | Inlet Condition | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wotzka and Oberts (10) | McCarrons Wetland Treatment System | Urban | NA | Detention pond | Constructed | 29.7 | 600 | 5.0% | 0.05-0.2 | 2.3-9.7 | 24 days | 2.5 | Diffuse | h |
| | | | | Wetland | Constructed | 6.2 | 600 | 1.0% | | | | | | |
| | | | | System | Constructed | 35.9 | | 6.0% | | | | | | |
| Hickok et al. (11) | Wayzata Wetland | Residential | NA | Wetland | Natural | 7.6 | 65.1 | 11.7% | 0.08 | NA | NA | NA | Discrete | i |
| | | Commercial | | | | | | | | | | | | |
| Barten (12) | Clear Lake | Urban | NA | Wetland | Constructed | 52.9 | 1,070 | 4.9% | 1.5 | 10 | 3-5 days | 0.5 | Diffuse | |
| Meiorin (13) | DUST Marsh | Urban | 93 | Wetland: | | | | | 10-250 | 150 | 4-40 days | 4.7 | Diffuse | j |
| | | Agricultural | 7 | A | Constructed | 5 | — | — | | | | | | |
| | | | | B | Constructed | 6 | — | — | | | | | | |
| | | | | C | Constructed | 21 | 2,960 | 0.7% | | | | | | |
| | | | | System | Constructed | 32 | 2,960 | 1.1% | | | | | | |
| Morris et al. (14) | Angora Creek | Residential | NA | Wetland | Natural | NA | 2,816 | NA | 8.46 | NA | NA | NA | Diffuse | k |
| | | Forest | NA | | | | | | | | | | | |
| | Tallac Creek | NA | NA | Wetland | Natural | NA | 2,781 | NA | 8.68 | NA | NA | NA | Diffuse | |
| Scherger and Davis (15) | Pittsfield-Ann Arbor Swift Run | Residential | 45 | Detention pond | Constructed | 25.3 | 4,872 | 0.5% | 0-2,916 | 21-176 | 4-105 | 0-6 | Discrete | f |
| | | Commercial | 19 | Wetland | Natural | 25.5 | 1,207 | 2.1% | 0-166 | 15-60 | 12-82 | 0-3 | Discrete | |
| | | Agriculture | 13 | | | | | | | | | | | |
| | | Open | 23 | | | | | | | | | | | |
| ABAG (16) | Palo Alto Marsh | Residential | 62 | Wetland | Natural | 613 | 17,600 | 3.5% | 150-320 | 400-750 | 30 | 1-6 | Discrete | l |
| | | Commercial | 12 | | | | | | | | | | | m |
| | | Open | 26 | | | | | | | | | | | |
| Jolly (17) | Long lake Wetland-Pond Treatment System | Agriculture | 100 | Wetland/ pond | Constructed | 1.5 | 18 | 8.3% | 0.01 | 1.5 | NA | 0.5-8 | Diffuse | n |
| Oberts et al. (18) | Tanners Lake | Residential | NA | Pond | Constructed | 0.07 | 1,134 | Neg. | NA | 0.1 | NA | 3.0 | Discrete | o |
| | McKnight Lake | Residential | NA | Pond | Constructed | 5.53 | 5,217 | 0.1% | NA | 13.2 | NA | 4.9 | Discrete | |
| | Lake Ridge | Residential | NA | Wetland | Constructed | 0.94 | 531 | 0.2% | NA | 2.0 | NA | 4.8 | Discrete | |

**Table 3. Wetland Geographic and Hydraulic Characteristics (continued)**

| Study | System Name | Watershed Land Use | % Land Use | System Type | Constructed/ Natural | Wetland Size (acres) | Watershed Size (acres) | Wetland/ Watershed Ratio | Average Flows ($ft^3$/sec) | Basin Volume (acre-ft) | Detention Time (hr) | Depth (ft) | Inlet Condition | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Carver Ravine | Residential | NA | Wetland/ pond | Constructed | 0.37 | 170 | 0.2% | NA | 1.0 | NA | 2.0 | Discrete | |
| Reinelt and Horner (19, 20) | B31 | Urban | NA | Wetland | Natural | 4.9 | 461.7 | 1.1% | 1.5 | 0.03–0.43 | 3.3 | NA | Discrete | p |
| | PC12 | Rural | NA | Wetland | Natural | 3.7 | 214.8 | 1.7% | 0.7 | 0.05-0.60 | 2.0 | NA | Discrete | q |
| Rushton and Dye (21) | Tampa Office Pond | Commercial | 100 | Wetland | Constructed | 0.35 | 6.3 | 5.6% | NA | 0.32 | NA | 0-1.5 | Discrete | r |
| Hey and Barrett (22) | Des Plaines River Wetland Demonstration Project | Agriculture | 80 | Wetland: | | | | | | | | | | |
| | | Urban | 20 | 3 | Constructed | 5.6 | — | — | 5 | NA | NA | 1 | Discrete | s |
| | | | | 4 | Constructed | 5.6 | — | — | 0.6 | NA | NA | 1 | Discrete | |
| | | | | 5 | Constructed | 4.5 | — | — | 4 | NA | NA | 1 | Discrete | |
| | | | | 6 | Constructed | 8.3 | — | — | 1 | NA | NA | 1 | Discrete | |

NA = Not available

System = summary information

a Short-circuiting was observed during several storms.

b The wetland is not a basin but similar to a grassy swale.

c Design configuration suggests little short-circuiting occurred.

d Generally sheet flow exists within the artificial wetland.

e The major influent to these natural wetlands is discrete channelized flow.

f The schematic suggests large areas of dead storage exist.

g Short-circuiting was not discussed by the author.

h Three discrete inlets help to minimize short-circuiting and dissipate surface water energy.

i Design configuration suggests minimal short-circuiting existed regardless of a single discrete inlet.

j Design configuration suggests little short-circuiting occurred due to long and narrow wetland basins.

k Flow occurs as channelized flow until the storm volume is large enough to force sheet flow through the meadowlands.

l Water level and volume are controlled by the tidal cycle.

m Channelized flow exists until the tide increases, causing the surrounding marsh to become inundated.

n Entire system consists of a sedimentation basin, grass filter strip, constructed wetland, and deep pond.

o Monitoring occurred during a dry period.

p Storm flows reduce detention times.

q Channelization reduced effective area in wetland.

r Overflow from adjacent wetlands occurred during extremely high water; leak and breach problems occurred during study.

s Water is pumped to the system from the river (drainage area of 210 square miles) for 20 hr/wk.

mulates stormwater flows within the system and discharges effluent slowly over days or weeks, depending on the interval between storms. Thus, the water collected at the discharge from the DUST marsh is probably a mixture of water that entered from the previous storms.

The type of inlet structure and the flow patterns through wetland areas also can significantly affect pollutant removal efficiencies. Morris et al. (14) found that sheet flow (as opposed to channelized flow) was the most critical factor in the effectiveness of meadowland treatment. This finding is consistent with the theory that shallow, vegetative overland flow decreases velocities and increases sedimentation. In addition, close contact with the soil matrix was found to increase assimilation of nutrients and bacteria. Brown (9) found that an undefined inflow (multiple input locations) to the wetland, which results in better dispersion of incoming load, was critical in the effectiveness of the wetland. An undefined inflow reduced short-circuiting and increased mixing and contact of the stormwater with the soil and plant substrates.

The change in seasons has been considered another important factor in the effectiveness of wetland treatment of storm runoff. Typical factors of seasonality are evapotranspiration rates and seasonal productivity and decay of plant and animal life. Removal efficiencies in wetlands located in areas with strong seasonal variation may vary significantly between seasons. For example, Meiorin (13) reported that high summer evapotranspiration rates caused a 200- to 300-percent increase in the total dissolved solids concentrations within the DUST marsh. Furthermore, high productivity during warm periods can lead to decreases in nutrients and increases in biochemical oxygen demand (BOD) and suspended solids. Morris et al. (14) reported that flushing and leaching effects of spring snowmelt caused an increase in total Kjeldahl nitrogen and organic carbon in flows leaving the Tahoe Basin meadowland. Harper et al. (5) reported that detention times greater than 2 days caused an increase in the export of orthophosphorus from the Hidden Lake wetland.

Hickok et al. (11) described microbial activity as the most important factor affecting phosphorus removal. Other factors that probably cause variations in the reported pollutant removal effectiveness include maturity of the wetland, the buildup of nutrients and heavy metals in a wetland system, particle-size distribution (which affects the settling of suspended sediments), and maintenance practices performed at a wetland.

## Comparison of Factors Affecting Reported Treatment Efficiencies

This study reviewed data on removal efficiencies for 26 different wetland systems. The study evaluated the following factors regarding their effects on wetlands pollutant removal performance:

- Constructed versus natural systems.
- Vegetation types found in the wetland.
- Land-use types draining to the wetland.
- Area of the wetland system compared with the contributing watershed.
- Estimated average storm-flow quantities draining to the wetland.
- Inlet types.

These factors affected only a few meaningful direct relationships. This was because of the limited amount

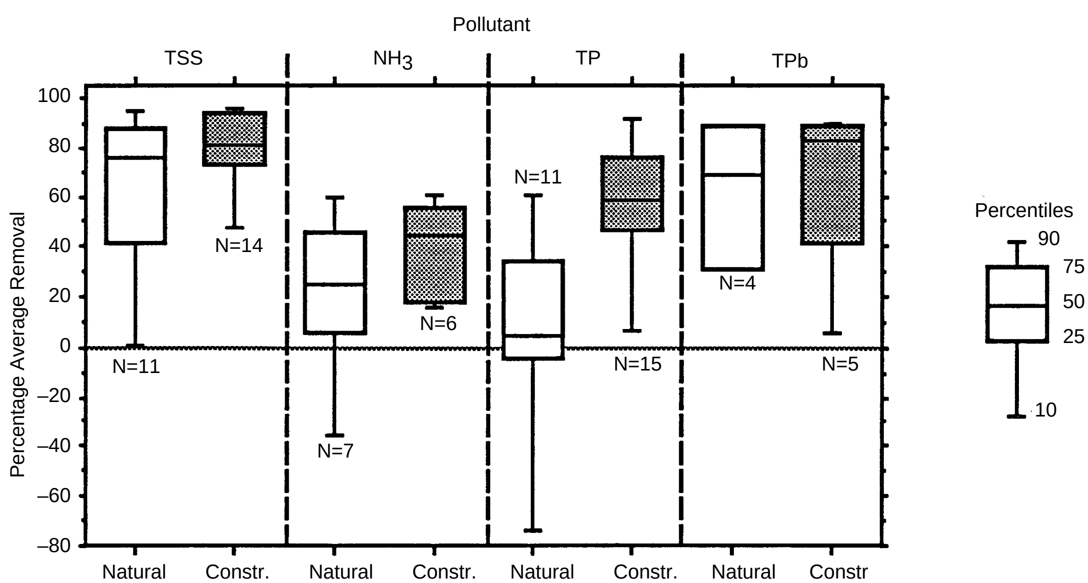



**Figure 3. Box plot percentiles comparison of site average pollutant removals for natural and constructed wetland systems: TSS = total suspended solids, $NH_3$ = ammonia, TP = total phosphorus, TPb = total lead, and N = number of wetland sites.**

of data available to determine these relationships as well as the multiple factors that affect performance. Without a large database, a meaningful multiple regression analysis was not possible.

Several trends, however, were noted. First, constructed systems generally had a higher average removal performance than natural systems, with less variability. Second, larger wetlands compared with their tributary watershed areas also showed the same trend: a higher average removal performance, with less variability. Figure 3 presents TSS, TP, $NH_3$, and TPb in a percentile box plot for the constructed and natural systems. Note that, in all cases for the pollutants summarized, constructed systems showed a higher average and median performance level. More significant, however, is the difference in variability between the two types of wetlands. Constructed sites were much less variable. This is not a surprising finding, given that constructed systems have generally been designed to handle expected incoming flows and to minimize short-circuiting. They should generally show a higher performance level with more consistency.

Investigators also looked at the area of the wetland system compared with the size of its contributing watershed. Regression of the wetland to watershed area ratio

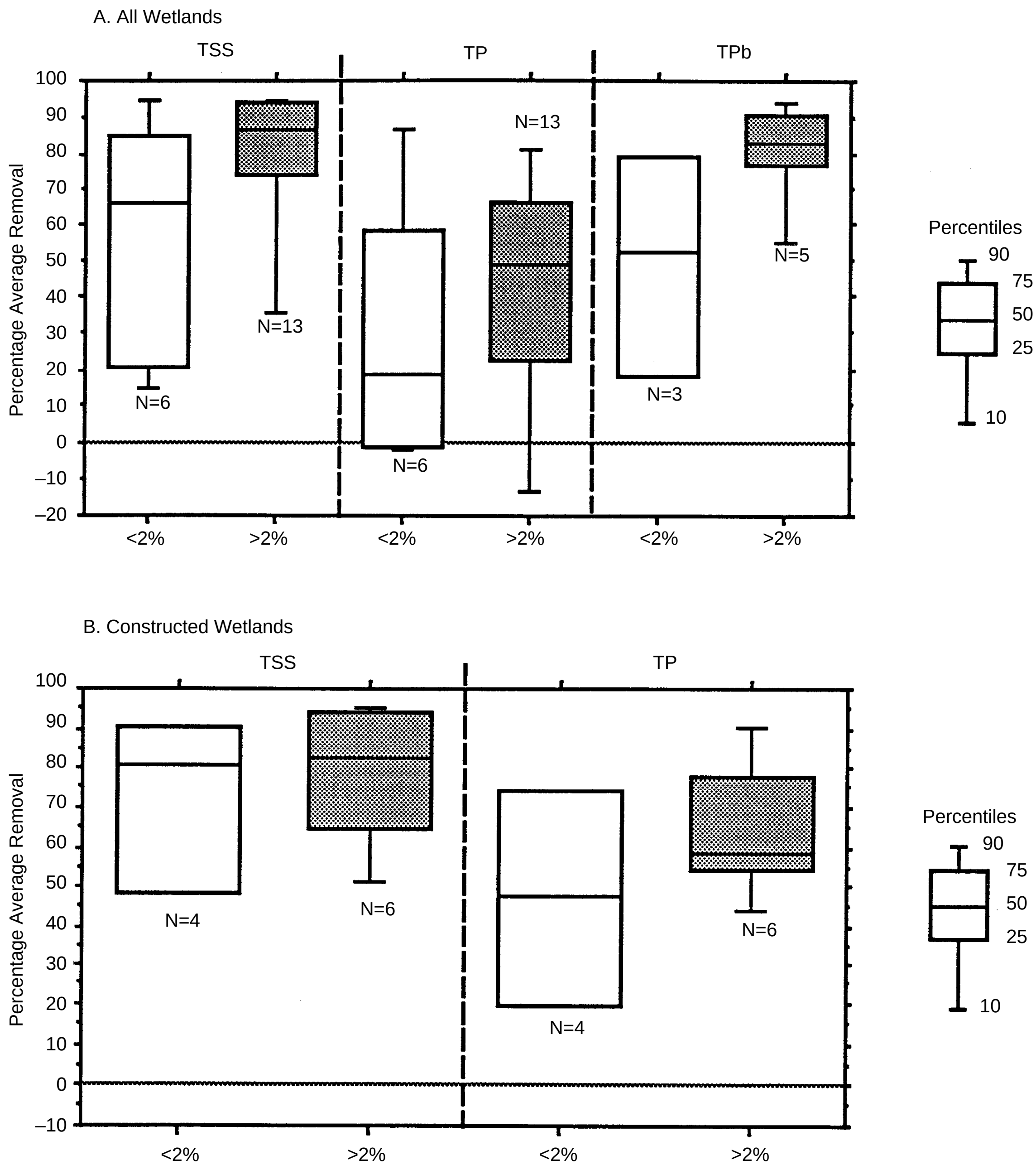



**Figure 4. Average site percentile box plots for TSS, TP, and TPb pollutant removals for wetlands with less than 2 percent and greater than 2 percent wetland-to-watershed size ratios (WWAR): N = number of wetland sites, TSS = total suspended solids, TP = total phosphorus, and TPb = total lead.**

(DAR) to pollutant removal performance did not reveal good direct relationships. Grouping sites according to a greater than or less than 2 percent DAR, however, did result in some general trends. Figure 4 presents performance results for all wetland systems with reported tributary watershed areas. In general, the larger DAR wetlands had higher performance levels, with less variability. This analysis included all wetland sites, natural and constructed. To separate out the effects of natural versus constructed systems, Figure 4 also presents a similar analysis for constructed sites only. Generally, for constructed sites the trends are the same, although the differences in performance levels and variability in performance are much less. The data indicate that carefully constructed systems can probably mitigate the importance of DAR as a factor in determining performance. Therefore, at this time we are not suggesting that 2 percent minimum DAR is a proper design criteria for constructed wetlands.

The Jackson Lake wetland is an example of a wetland with a small DAR that still achieved excellent performance (85 percent TSS removal). The DUST marsh and the Lake Ridge wetlands also showed high performance levels (76 and 85 percent TSS removals, respectively). One factor that explains the DUST marsh performance is that it is an “off-line” device:  it only receives flow volumes up to a certain flow rate, then bypasses high flows. This type of design is particularly appropriate for wetlands receiving stormwater from larger catchments relative to wetland size.

To better measure the capacity of a wetland to treat runoff from a given watershed would entail evaluating average storm runoff volumes of wetland tributary areas with wetland storage volumes and/or contact surface areas. The data from the studies, however, did not consistently include data on rainfall statistics, percent impervious for land uses, specific percentages for land uses in a catchment, flow volumes to the wetland, capacity of the wetland system, and surface areas for contact with stormwater (including soils and plants). Therefore, we were not able to analyze the wetland systems using this approach. The summary of this paper contains some recommendations regarding reporting information for future studies, so that such analyses can be completed.

Finally, no good studies or documentation exists regarding maintenance activities in wetlands that are treating stormwater. In addition, the need for maintenance and level of maintenance are not well understood or documented. These activities could affect performance characteristics of wetlands, particularly over the long term.

## Assessment of the Reliability of Wetland Data

There are various difficulties in comparing one wetland study to another. Table 4 presents a list of the selected literature, including information on the sampling characteristics that each study employed. The table shows that the studies identified generally lasted a year or less. There was quite a variation in the number of samples collected (from 3 to about 150), as well as in the sampling methods used (i.e., grab sample or samples versus composite sample for an event). These factors all contribute to the difficulty of comparing results from the different studies. Another complication in comparing the performance of wetlands involves the method of quantifying their effectiveness.

## Noted Impacts of Stormwater Runoff on Wetland Biota

Many researchers have expressed concern over the impact of the quantity and quality of stormwater runoff on wetland biota, especially in natural wetlands (27, 28). The quantity of stormwater runoff determines the hydrologic characteristics of a wetland, including the average and extreme water levels and duration and frequency of flooding. Stormwater runoff also contains pollutants that can adversely affect wetland biota if accumulated in high concentrations. The hydrology of a wetland is one of the most important factors in establishing and maintaining specific types of wetlands and wetland processes (29). Hydrology is a key factor in wetland productivity, vegetation composition, nutrient imports, salinity balance, organic accumulation, sedimentation transport, and soil anaerobiosis.

Few of the reports reviewed indicated concern regarding the effects of contaminants in urban stormwater on wetland systems. Many of the reports referenced studies performed in wetlands receiving sewage effluents or industrial discharges of some type. Urban runoff, especially from residential watersheds, frequently has much lower concentrations of pollutants than do sewage effluents or industrial discharges.

Sediments typically constitute the most significant store of toxic substances available to organisms in a wetland (29). Plants can take up metals and toxic organic compounds from the sediments, thus introducing them into the food web (30-32). Both metals and organics tend to be adsorbed to finely divided solids, depending on conditions such as pH, oxidation-reduction potential, and salinity (33). The way a metal is complexed determines its availability to plants (33).

Water resides longer in wetlands compared with more swiftly moving waters because of the flatness of wetlands and the filtering action of the vegetation. This longer residence time allows suspended solids to drop out and be retained (32, 33). Woodward-Clyde Consultants (34) found that the greatest concentration of metals in sediments occurred at the location nearest the stormwater inlet and declined with distance from the inlet. They found the sediment concentration and bioavailabil-

**Table 4. Sampling Characteristics From the Wetlands Reviewed**

| Study | Location | Time of Study | Length of Study | Type of Sample | Number of Storms Monitored | Method of Computing Efficiencies |
|---|---|---|---|---|---|---|
| Martin and Smoot (4) | Orange County, FL | 1982–1984 | 2 years | 7 multigrab, 6 composite | 13 | ROL |
| Harper et al. (5) | FL | 1984–1985 | 1 year | Composite | 18 | ER |
| Reddy et al. (6) | Orange County, FL | 1977–1979 | 2 years | Single grab | Approx. 150 | MC |
| Blackburn et al. (7) | Palm Beach, FL | 1985 | 1 year | Single grab | 36 | MC |
| Esry and Cairns (8) | Tallahassee, FL | 1985 | NA | NA | 1 | NA |
| Brown (9) | Twin Cities Metro Area, MN | 1982 | 1 year | Composite | 5–7 | SOL |
| Wotzka and Oberts (10) | Roseville, MN | 1984–1988 | 2 years | Composite | 25 | ROL |
| Hickok et al. (11) | MN | 1974–1975 | 10 months | NA | NA | SOL |
| Barten (12) | Waseca, MN | 1982–1985 | 3 years | Composite | 27 | ER |
| Meiorin (13) | Coyote Hills, Fremont, CA | 1984–1986 | 2 years | Composite | 11 | SOL |
| Morris et al. (14) | Tahoe Basin, CA | 1977–1978 | 1 year | Single grab | Approx. 75 | MC |
| Scherger and Davis (15) | Ann Arbor, MI | 1979–1980 | 8 months | Composite | 7 | SOL |
| ABAG (16) | Palo Alto, CA | 1979 | 3 months | Composite | 8 | ER |
| Jolly (17) | St. Agatha, ME | 1989 | 5 months | Composite | 11 | SOL |
| Oberts et al. (18) | Ramsey–Washington Metro Area, MN | 1987–1989 | 2 years | Composite | 7–22 | SOL |
| Reinelt and Horner (19, 20) | King County, WA | 1988–1990 | 2 years | Composite | 13 | SOL |
| Rushton and Dye (21) | Tampa, FL | 1989–1990 | 12 months | Composite | 3–8 | ER |
| Hey and Barrett (22) | Wadsworth, IL | 1990 | 8 months | Discrete | Continuous | SOL |

ER = event mean concentration
MC = mean concentration
NA = not available
ROL = regression of event loads
SOL = sum of event loads

ity of copper, lead, and zinc to be at or near background levels in the downstream marsh area.

Plants take more metals from the sediment than from the water column. Phytoplankton, however, can remove metals directly from the water, releasing them to the sediments or to the water upon death (35). In general, far greater amounts of metals remain in the sediment than are taken up by plants (36-39). Some plants are apparently able to exclude toxic metals selectively. Organic compounds undergo many of the same processes in wetlands as metals, including adsorption to sediments and plant uptake. In addition, they can be biodegraded.

The uptake of toxic materials by plants can introduce these materials into the grazing and detrital food chains, with potentially deleterious effect. Metals from sewage effluents introduced to wetlands tend to accumulate in the food chain (32). Finally, the relative responses of plants and animals to toxic metals and organic compounds indicate that these contaminants are more likely to affect animals negatively.

## Comparison of Wetland and Detention Basin Performance

Detention facilities have traditionally been constructed to control stormwater runoff quantities. These facilities temporarily store stormwater runoff and later release the water at a lower flow rate. Design of detention basins and ponds can provide for water quality enhancement by including a permanent pool of water and inlet and outlet structures to maximize detention. Quiescent velocities within the basins allow sediments to settle out of the stormwater and undergo chemical and biological removal processes. Detention basins usually do not have vegetation within the permanent pool, but the banks may be planted with grasses for erosion control.

Detention basin/constructed wetland treatment systems have been recommended for stormwater treatment (4, 10, 40). Typically in these systems, stormwater runoff discharges to the detention basin, which then releases the water to the wetland for additional treatment. The detention basin can provide pretreatment for the wetland, reducing the sediment and pollutant loads to the wetland. In other instances, detention basins and constructed wetlands are competing alternatives under consideration for stormwater treatment. To make a decision, the designer or planner requires knowledge of the relative pollutant removal efficiencies, environmental impacts, maintenance requirements, and costs of the two alternatives.

To further illustrate how those systems compare, the following discussion focuses on the results from a case study of the McCarrons treatment facility system, which compared the performance of wetlands with that of detention basins through simultaneous monitoring of both systems. Wotzka and Oberts (10) presented a paper discussing the combined detention-wetland stormwater treatment facility. The McCarrons treatment facility consisted of a 30-acre detention basin with an average depth of 1.2 ft and a 6.2-acre constructed wetland with an average depth of 2.5 ft. The detention basin received stormwater and then discharged to the wetland. The contributing watershed consisted of 600 acres of primarily urban land use. The predominant vegetation in the wetland consisted of cattails with other emergent plant species.

Overall, the system produced very good results. The detention basin proved to be more effective than the wetland in reducing several pollutants. For example, Table 5 lists removal efficiencies for the detention basin and wetland.

Wotzka and Oberts (10) discussed some of the possible explanations for the good results of the detention basin and for its differences from the wetland. In general, they believed that the treatment efficiencies were lower in the wetland due to pretreatment by the detention basin. They stated that the inflows into the detention basin spread equally around the perimeter of the detention basin, thus dissipating the entry velocities of the storm runoff. Dissipation of inflow energy probably promoted settling and minimized short-circuiting.

**Table 5. Removal Efficiencies (%) for Detention Basin and Wetland**

| Parameter | Detention Basin | Wetland |
|---|---|---|
| TSS | 91 | 87 |
| TP | 78 | 36 |
| TN | 85 | 24 |
| TPb | 85 | 68 |

Wotzka and Oberts (10) suggested that the percentage of phosphorus in the dissolved and particulate phases affected the reduction potential. They found that more than 80 percent of the phosphorus was in the particulate form, resulting in high removal efficiencies due to settling. Apparently, the wetland did not perform as well as the detention basin because of the periodic release of nutrients from decaying vegetation and the fact that significant pretreatment had occurred. The authors also suggested that the high removal of phosphorus was due in part to the newly exposed soils on the bottom of the detention basin. They explained that the newly exposed soils probably had more adsorption capacity available than the soils in the wetland further downstream. They also suggested that saturated soil conditions could lead to a reduction in phosphorus removal.

In conclusion, this study indicated that the detention basin performed better than the wetland system. This may be misleading, however, because the wetland received pretreated waters from the detention basin. The detention basin removed the fraction of pollutants that were more readily settled and treated, leaving the wetland with the more difficult-to-treat, finer particulates and dissolved pollutants.

## Summary

Wetlands have a good capability for removing pollutants from stormwater runoff. Several factors contribute to and influence removal efficiencies, including sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. The reported removal efficiencies are, as expected, quite variable. For the wetlands systems reviewed, removal efficiencies for TSS had a median of 76 percent. TSS removal is a good indicator of pollutant removal potential for heavy metals and phosphorus, as well as other pollutants associated with fine particulate matter. Constructed wetlands tended to be more consistent than natural wetlands in their removal of TSS and the other analyzed parameters. Wetlands have also shown the ability to remove dissolved metals. Nutrient removal in wetlands is variable, depending on both wetlands characteristics and seasonal effects.

Because many dissimilarities exist between the wetlands studied, wetlands stormwater pollutant removal efficiencies vary widely. Properly designed, constructed, and maintained wetlands, however, can be effective pollution control measures. Examining additional wetlands in a variety of geographical areas, as well as long-term pollutant removal efficiencies, is definitely necessary.

A significant issue, however, involves whether stormwater control measures should include natural wetland systems. In general, natural wetlands have been found to be somewhat less predictable than constructed wetlands in terms of pollutant removal efficiency. This difference may be due to the fact that constructed wetlands have generally been engineered specifically to provide favorable flow capacity and routing patterns. As a result, they tend to detain inflows for longer periods and have less short-circuiting than many natural systems.

People often question the appropriateness of using a natural, healthy wetland for such purposes. Their concern is whether the modified flow regime and the accumulation of pollutants will result in undesirable environmental effects. There are many situations where natural wetlands have been receiving urban runoff for years. Some of these wetlands reflect significant degradation because of many factors, including urban runoff, whereas others have been less affected. A general consensus from the literature is to discourage the use of a healthy natural wetland for stormwater pollution control. In the case of rehabilitating a natural but degraded wetland, modifications should ensure that the applied runoff receives sufficient pretreatment. One pretreatment technique would be to use pond areas to provide an opportunity for suspended materials to settle out before the flows enter the wetland. Other possible options include routing inflows to the wetlands through upstream grass swales, oil/water separators, heavily vegetated areas (e.g., thick, shallow cattail areas), and overland flow areas.

These techniques would not only act on solids but also on floatables such as oil and water. Although little evidence exists of problems in wetlands that have been receiving stormwater runoff, the available data are quite limited, and developing additional information on impacts is critical. Additional studies on the impacts to biota should be undertaken.

In addition, the maintenance needs of wetland systems that treat stormwater merit further study. Such maintenance activities could include sediment removal and plant harvesting. Further studies should address the need for and the frequency and appropriateness of maintenance.

Gathering more information on wetland effectiveness would benefit design development procedures for sizing wetland treatment facilities. There is currently not enough information in the existing literature to develop design guidelines for constructed wetland treatment systems. Additional studies are needed to broaden the type of wetland systems reviewed, develop information on long-term performance, and evaluate seasonal characteristics of wetland performance.

A review of the data available on wetland stormwater treatment effectiveness revealed that most studies did not contain enough information on study and wetland characteristics to analyze in detail the factors affecting treatment performance among different wetlands. Table 6 presents a summary of the information that would hopefully provide a better means to compare wetland

**Table 6. Suggested Reporting Information for Studies That Assess the Ability of Wetlands To Treat Stormwater Pollution**

**Wetland classification**

- Constructed or natural or combination wetland?

**Vegetation species**

**Vegetation density** (percentage open and vegetated)

**Vegetation types** (submerged, emergent, floating)

**Wetland size**

**Wetland aspect** (length-to-width ratio)

**Side slopes**

**Soil type and depths**

**Watershed size** (acres)

**Watershed land use** (percent residential, industrial, agricultural, undeveloped, etc.)

**Watershed percent impervious** (percent impervious area)

**Rainfall data/statistics**

- Average rainfall during study (in./year)
- Average number of storms per year
- Average storm intensity (in./hr)
- Average storm duration (hr)
- Average time between storms (days)

**Low flow inflow rate(s)**

**Ground-water interaction?**

**Total flow from average storm**

**Wetland volume** (maximum storage volume)

**Average detention time for average storm** (hours)

**Water depth** (minimum, maximum, average)

**Inflow condition** (discrete or diffuse inlets)

**Pretreatment of inflow** (settling forebays, overland flow, detention basin, grassed swales, etc.)

**Maintenance practices (including frequency)**

- Plant harvesting?
- Flushing?
- Sediment removal?
- Chemical treatment?
- Other maintenance?

**Provide hydrology and water quality data for all storms monitored**

**Type of samples** (grab or composite)

**Number of storms monitored**

**Method used to compute pollutant removal efficiencies**

**Dominant removal mechanisms** (sedimentation, adsorption, filtration, biochemical, etc.)

designs and treatment effectiveness from different wetland systems. This type of information could be useful when comparing watershed to wetland characteristics regarding performance.

This paper compared watershed to wetland size ratios. A comparison of average storm volume to wetland volume would have made a better analysis of the effect of wetland "sizes" on treatment abilities. The currently available data, which predominantly present areas of wetlands and watersheds, did not allow for this kind of comparison. Percent impervious factors and therefore runoff volumes could be very different in different watersheds. Data such as percent imperviousness, land use information, and rainfall statistics, along with wetland volume information, would have allowed us to compare average runoff volumes, wetland volumes, and resulting performance characteristics.

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# *Constructed Wetlands for Urban Runoff Water Quality Control*

**Richard Horner**
**University of Washington, Seattle, Washington**

## Abstract

Like all options for urban runoff water quality control, constructed wetlands have their advantages, disadvantages, and limitations. To realize their advantages, avoid problems, and use them appropriately requires recognition and adherence to certain principles. A hallmark of true constructed wetlands is their structural diversity, which yields the substantial advantages of breadth in treatment capabilities and potential for ancillary benefits as well as the disadvantage of larger land requirements for equivalent service than alternative measures. Prerequisites for success are functional objectives for the project to achieve and a corresponding design concept based on the structural characteristics of natural wetlands that are responsible for effective performance of the identified functions. Critical implementation considerations are proper siting, sizing, configuring of design features, construction, and various aspects of operations. Careful site-specific hydrologic analysis must be performed to ensure a sufficient water supply to sustain a wetland. The basis for sizing is limited at present, but application of climatological statistics and existing knowledge of needed hydraulic residence times for given treatment objectives provide some foundation. Equal in importance to planning, siting, and sizing are shaping, contouring, vegetating, and following up with short- and long-term maintenance, for which specific guidance is offered.

## Background

### *Scope*

Wetlands specifically constructed to capture pollutants from stormwater runoff draining urban and agricultural areas are gaining attention as versatile treatment options. Several recent major pieces of work have covered constructed wetland treatment, including those by Hammer (1), Strecker et al. (2), Olson (3), and Schueler (4). This paper draws on these resources and is intended to offer a concise summary of the current state of stormwater treatment using constructed wetlands and the methods for developing projects. The paper was derived from a 1-day continuing education course on the subject at the University of Washington, for which a course manual is available (5). In particular, this paper emphasizes the fundamental concepts on which successful application is based.

More than 150 wetlands have been constructed in the United States to treat municipal and industrial, especially mining, wastewaters (2). No complete accounting of stormwater constructed wetlands exists, but their number is certainly fewer.

The two basic types of municipal and industrial systems are both forms of attached growth biological reactors: free water surface (FWS) and subsurface flow (SF), or vegetated submerged bed (VSB) (6). The first type is similar to natural wetlands, with a soil base, emergent vegetation, and water exposed to air. The second type has a soil base overlain by media, emergent vegetation, and a water level below the media surface. The majority of municipal and industrial applications, most of small scale, are of this type. The advantages of a submerged system in these applications are reduced odor, insect problems, and land requirements because of the greater surface area for biological growth offered by the media. The FWS type is generally more appropriate for stormwater applications, where usually no odor problem exists, flows vary widely, and often there is a desire to integrate the treatment system with the landscape and to provide ancillary benefits. This paper covers only the FWS type of system.

### *Legal and Regulatory Considerations*

From a legal and regulatory standpoint, “constructed wetlands” are designed, built, and continually maintained for the purpose of waste treatment. In this status, they are not regarded under the Clean Water Act as “waters of the United States.” Accordingly, no regulations apply to water quality within, but the discharge is regulated in the same way as any treatment system.

This designation is in contrast to wetlands built for such purposes as mitigation of wetland losses under Clean Water Act Section 404 or to develop waterfowl habitat, known as “created wetlands.” These systems have the same legal protections as natural wetlands, including prohibition on using them for the conveyance or treatment of waste. They usually have multiple functions, with any water quality improvement benefit being only incidental; entering water must be managed to prevent damage to any intended function. A constructed wetland also differs in purpose and legal status from a wetland “restoration,” the purpose of which is to return a degraded system with reduced acreage or functional ability to the condition preceding degradation. If the wetland is not completely restored but one or more functions are increased, it is termed an “enhanced wetland.” Restored and enhanced wetlands also have the same legal protections as natural wetlands.

A somewhat fuzzy issue with respect to constructed wetlands is their regulatory status if the principal purpose is waste treatment but ancillary benefits (e.g., wildlife habitat) are gained by design or incidentally. This situation is subject to interpretation by state and federal agencies. Such benefits are often among the objectives of project developers and are certainly possible to attain along with stormwater treatment in many circumstances; this paper provides advice on pursuing these objectives in a judicious way.

## *Constructed Wetlands in Relation to Alternative Methods*

Alternatives to constructed wetlands for general-purpose stormwater treatment include wet ponds, extended-detention dry ponds, infiltration basins and other devices that drain into ground water, filtration, and “biofiltration” through terrestrial or hydrophytic plants in swales or on broad surface areas. Constructed wetlands have both advantages and disadvantages relative to these other options. Principal advantages are:

- More diversity in structure than any alternative, which offers the potential for relatively effective control of most types of pollutants.
- Wider range of potential side benefits than any alternative.
- Relatively low maintenance costs.
- Wider applicability and more reliable service than infiltration.

Disadvantages of constructed wetlands include:

- Larger land requirements for equivalent service than wet ponds and other systems, especially if intended to serve quantity as well as quality control purposes.
- Relatively high construction costs.
- Delayed efficiency until plants are well established.
- Uncertainty in design, construction, and operating criteria, a drawback also hampering competitive methods.
- Public concern about nuisances that can develop with stormwater constructed wetlands without care in siting, design, construction, and operation.

## *Functioning of Constructed Wetlands*

### Pollutant Removal Mechanisms

Numerous physical, chemical, and biological mechanisms can potentially operate in constructed wetlands to trap and transform entering pollutants. Understanding these mechanisms is the basis for determining effective treatment systems. That understanding can inform the entire process, from conception of the project, through preliminary planning and all phases of implementation, and, finally, to the long-term operation of the system. Table 1 summarizes the various mechanisms, the pollutants that they affect, and features that can promote their operation.

Some beneficial features are controllable through choices made during the project development process, while others are largely outside of the designer’s influence, especially in a stormwater application. As can be seen in Table 1, some features are helpful in achieving multiple treatment objectives, but others are more specialized. Features that are largely under the project developer’s control and help achieve any objective are 1) increasing hydraulic residence time (HRT); 2) providing an environment that creates flow at a low level of turbulence; 3) propagating fine, dense, herbaceous plants; and 4) establishing the wetland on a medium-fine textured soil, or amending soils to attain that condition.

Somewhat more specialized features, still mostly controllable, include 1) circumneutral Ph, which advances microbially mediated processes such as decomposition and nitrification-denitrification and avoids the mobility of certain pollutants at extreme pH; 2) a relatively low level of toxic substances in the site soils and entering flow, also needed for microbes; and (3) high soil organic content, which advances adsorption and decomposition and can be attained by site selection or soil amendment. Even more specialized are measures that can aid phosphorus capture, one of the most difficult treatment objectives to achieve. High soil exchangeable aluminum and iron contents have been found to enhance phosphorus reduction (7) but would require special soil amendments where naturally lacking, which thus far is an undemonstrated option in a full-scale wetland system. Addition of precipitating agents is an active treatment measure that is difficult to apply in passive

**Table 1. Constructed Wetland Pollutant Removal Mechanisms**

| Mechanism | Pollutants Affected | Promoted By |
|---|---|---|
| **Physical** | | |
| Sedimentation | Solids, BOD, pathogens; particulate COD, P, N, metals, synthetic organics | Low turbulence |
| Filtration | Solids, BOD, pathogens; particulate COD, P, N, metals, synthetic organics | Fine, dense herbaceous plants |
| Soil incorporation | All | Medium-fine textured soil |
| **Chemical** | | |
| Precipitation | Dissolved P, metals | High alkalinity |
| Adsorption | Dissolved P, metals, synthetic organics | High soil Al, Fe (P); high soil organics (met.); circumneutral pH |
| Ion exchange | Dissolved metals | High soil cation exchange capacity |
| Oxidation | COD, petroleum hydrocarbons, synthetic organics | Aerobic conditions |
| Photolysis | COD, petroleum hydrocarbons, synthetic organics | High light |
| Volatilization | Volatile petroleum hydrocarbons and synthetic organics | High temperature and air movement |
| **Biological** | | |
| Microbial decomposition | BOD, COD, petroleum hydrocarbons, synthetic organics | High plant surface area and soil organics |
| Plant uptake | P, N, metals | High plant activity and metabolism and surface area |
| Natural die-off | Pathogens | Plant excretions |
| Nitrification | $NH_3$-N | Dissolved oxygen >2 mg/L, low toxics temperature >5-7°C circumneutral pH |
| Denitrification | $NO_3$ + $NO_2$-N | Anaerobic, low toxics, temperature >15°C |

Al = aluminum, BOD = biochemical oxygen demand, COD = chemical oxygen demand, Fe = iron, N = nitrogen, $NH_3$ = ammonia, $NO_2$ = nitrite, $NO_3$ = nitrate, P = phosphorus.

stormwater treatment systems subject to unpredictable and variable flow conditions.

Also outside the control of the designer and operator in a stormwater wetland is exploitation of the nitrification-denitrification processes to achieve nitrogen removal ultimately through evolution of nitrogen gas to the atmosphere. Full operation of the several steps in the bacterially driven processes requires alternating aerobic and anaerobic conditions at favorable temperatures, the first condition to permit oxidation to nitrate and the second to allow nitrate reduction to free $N_2$ gas. While these processes can be brought under some control in municipal and industrial treatment applications through timing of flow introduction, that degree of management is usually not possible in stormwater cases.

### Expected Performance of Constructed Wetlands

Strecker et al. (2) conducted a full literature review of the use of both natural and constructed wetlands for controlling stormwater pollution. This review considered more than 140 papers and reports and assembled detailed information on 18 locations throughout the United States. Median pollutant removals in constructed wetlands were 80.5 percent for total suspended solids (TSS), 44.5 percent for $NH_3$-N, 58.0 percent for total phosphorus (TP), 83.0 percent for lead (Pb), and 42.0 percent for zinc (Zn). Coefficients of variation (standard deviation/mean) for these contaminants ranged from 27.7 to 56.1 percent, pointing out that both substantially higher and lower performances than median levels were reported. Pollutant reductions in constructed wetlands were overall higher than in natural wetlands, which was attributed to the specific design features and more intensive management of the constructed systems.

Schueler (4) estimated the performance potential of wetlands designed as he recommended based on the overall literature (Table 2). He considered these efficiencies to be provisional pending monitoring of the new systems.

**Table 2. Projected Long-Term Pollutant Removal Rates for Wetlands Constructed as Recommended by Schueler (4)**

| Pollutant | Removal Rate (percent)[a] |
|---|---|
| TSS | 75 |
| TP | 45[b] |
| Total nitrogen (TN) | 25[c] |
| BOC, COD, total organic carbon | 15 |
| Pb | 75 |
| Zn | 50 |
| FC | Two orders of magnitude |

[a] Lower by an unknown amount for pocket wetlands (see below for description of wetland types).
[b] 65 percent in pond/marsh system.
[c] 40 percent in pond/marsh system.

## *The Constructed Wetland Design and Implementation Process*

Developing a constructed wetland treatment system should proceed carefully through a number of steps, as follows:

1. Planning the project.

2. Selecting the site.
3. Sizing the facility.
4. Configuring the facility, and incorporating design features that promote pollution control.
5. Designing for ancillary benefits.
6. Selecting vegetation and developing a planting plan.
7. Constructing the facility and establishing vegetation.
8. Developing and implementing an operation and maintenance plan.

The remainder of this paper explains these steps.

Project development for a constructed wetland must be a team effort, with a number of skills and specialties represented, including:

- Hydrology
- Water quality
- Soils
- Botany
- Wildlife ecology
- Landscape architecture
- Design engineering
- Construction engineering
- Stormwater facility maintenance

It bears emphasizing that a high level of hydrologic expertise should be employed to ensure that the most essential need—water supply—is met.

## *Planning and Site Selection*

### Preliminary Planning Considerations

Constructed wetland projects should be planned systematically and on a watershed scale as much as possible. This comprehensive analysis should start with consideration of management and source control practices that can prevent pollutant release. Another general consideration that should receive attention is the overall place of constructed wetlands and how they can best be used in conjunction with other treatment practices.

If the constructed wetland option is pursued, project objectives should be stated in functional terms, for example:

- The type of protection to be provided to the receiving water, pollutants to be controlled, and levels of control to be achieved (if possible).
- Benefits to be provided in the areas of, for example, open space, aesthetics, and recreation.
- Animals and life stages for which habitat is to be provided.

The potential for constructed wetlands to play a key role in stormwater management has developed from the understanding of natural wetland functioning gained during the past 20 years. Natural wetlands serve their recognized functions, which include providing flood flow control, water quality improvement, and ecological benefits, as a consequence of their structure and the interactions among their component parts. Mimicking these functions in an engineered system can best be done with reference to natural models. Therefore, using nearby natural wetlands as reference models for the configuration and planting of the wetland to be designed is strongly recommended. The reference system(s) should be characterized through formal observations and measurements of its hydrology, water quality, soils, vegetation, and, if appropriate, animal habitat and species. It is not necessary to mimic the reference plant community entirely, but studying it provides an idea of how the constructed system is likely to evolve.

With the natural model(s) in mind, a design concept can be developed. Schueler (4) proposed four basic stormwater wetland designs:

- *Shallow marsh:* A system with a relatively large land requirement that generally is used in larger drainage basins.
- *Pond/Marsh:* A two (or more) cell arrangement with a land requirement that is reduced by a relatively large deep pool.
- *Extended-detention wetland:* A more highly fluctuating hydrologic system in which the land requirement is reduced by adding high marsh to the shallow marsh zone.
- *Pocket wetland:* A design for smaller drainage basins (0.4 to 4 hectares) that may provide insufficient baseflow for permanent pool maintenance and cause greater water level fluctuations.

Figure 1 illustrates the pond/marsh type design. For diagrams of the other designs, see Schueler (4). Table 3 summarizes some of the principal selection criteria for the respective wetland types.

To complete preliminary planning, the design process and its aftermath should be organized. The following list of general principles for project design and implementation, derived from the various comprehensive references cited earlier, provides guidance for these steps:

- Design and implement with designated objectives constantly and clearly in mind.
- Design more for function than for form. Many forms can probably meet the objectives, and the form to which the system evolves may not be the planned one.

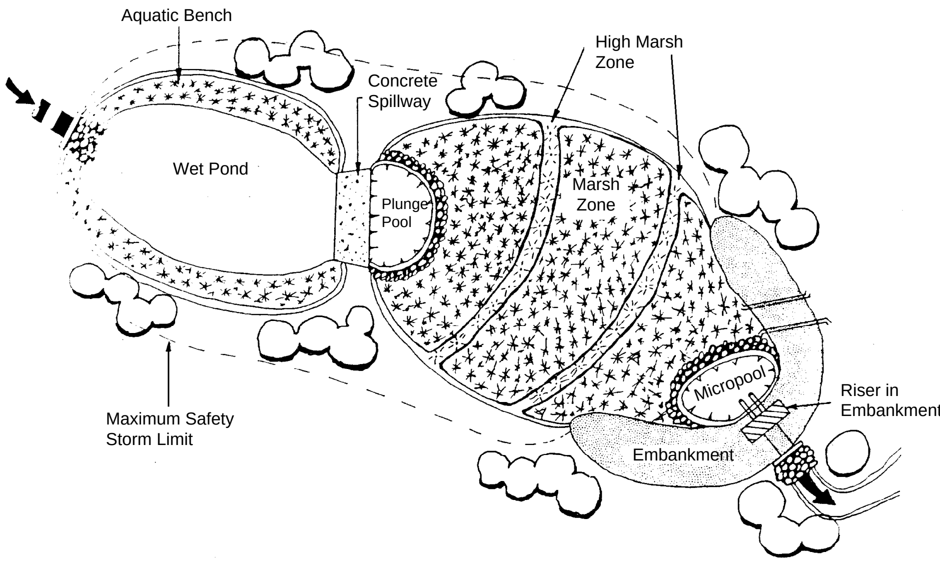


**Figure 1. Two-cell pond/marsh design concept (4).**

**Table 3. Design Concept Selection Criteria (adapted from Schueler [4])**

| Attribute | Shallow Marsh | Pond/ Marsh | Extended-Detention Wetland | Pocket Wetland |
|---|---|---|---|---|
| Minimum wetland-to-watershed area ratio | 0.02 | 0.01 | 0.01 | 0.01 |
| Minimum watershed area (hectares) | 10 | 10 | 4 | 0.4 |
| Dry weather baseflow | Yes | Yes | Not necessarily | Not necessarily |
| Relative potential for ecological benefits | High | High | Moderate | Low to moderate |

- Design relative to the natural reference system(s), and do not over-engineer.
- Design with the landscape, not against it (e.g., take advantage of natural topography, drainage patterns).
- Design the wetland as an ecotone. Incorporate as much "edge" as possible, and design in conjunction with a buffer and the surrounding land and aquatic systems.
- Design in structural complexity for beneficial distribution of water (e.g., its contact with vegetation and soils) and for biological advantages, as appropriate to objectives.
- Design to protect the wetland from potential high flows and sediment loads.
- Design to avoid secondary environmental and community impacts.
- Plan on sufficient time for the system to develop before it must satisfy objectives. Attempts to short-circuit ecological processes by overmanagement usually fail.
- Design for self-sustainability and to minimize maintenance.

### Constructed Wetland Site Selection

Prospective constructed wetland sites should be evaluated carefully and a selection made after analyzing a number of conditions. Brodie (8) presented a generalized site screening procedure, which is reproduced in Figure 2. Table 4 summarizes the major considerations that should enter into this analysis. Application of these recommendations implies a significant data-gathering effort, which is essential at this sensitive stage in project development.

The need for a sufficient water supply to sustain a wetland is an especially important consideration; neglect of this consideration has led to constructed and created wetlands that are not viable. Thus, a water balance should be carefully established using the following formula to ensure that water availability and inputs at least balance outputs at all periods throughout the year:

$$I + P + D + S > O + E + R$$

where
I = surface inflow
P = precipitation
D = ground-water discharge

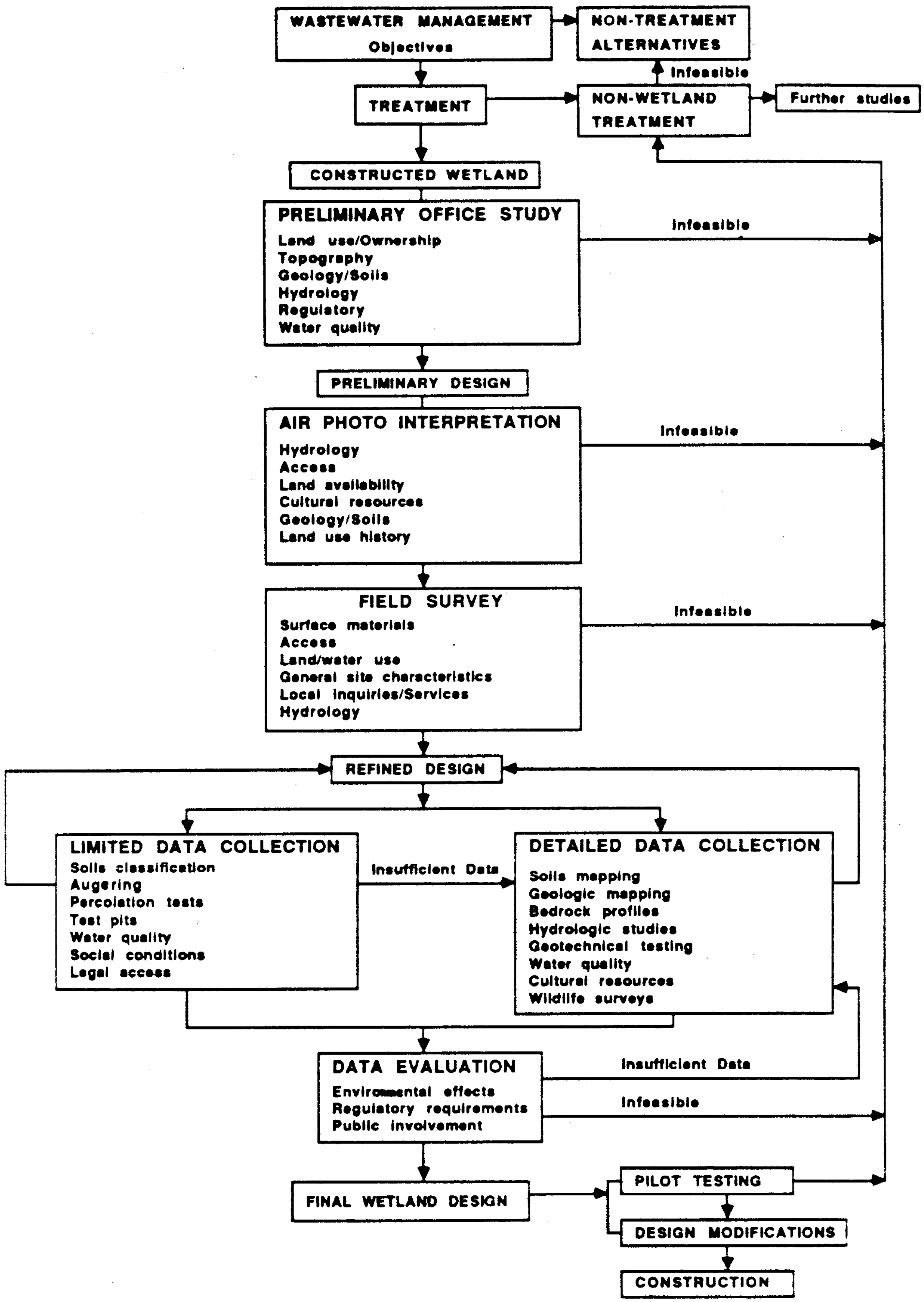


**Figure 2. A generalized methodology for screening sites for constructed wetlands (8).**

**Table 4. Considerations in Constructed Wetland Site Selection**

| Category | Considerations |
|---|---|
| Land-use and general factors | Land availability<br>Existing site use and value<br>Site problems (e.g., previous dumping, utility lines)<br>Adjacent land use and value<br>Connection to wildlife corridors and potential for adjacent areas to be biological donors<br>Public opinion<br>Accessibility for construction and maintenance<br>Ability to control public access according to project objectives |
| Environmental and regulatory factors | Federal, state, and local laws and regulations<br>Avoidance of archaeological and cultural resources<br>Avoidance of critical wildlife habitat areas |
| Hydrology and water quality factors | Water supply reliability<br>Low potential for disruptive flooding<br>Water supply of adequate quality to sustain biota<br>Low potential for the project to adversely affect downstream water bodies and adjacent properties and their water supplies<br>Need for lining to retain water or avoid ground-water contamination |
| Geology factors | Preferably flat or gently sloped topography<br>Adequate soil development<br>Sufficient depth to bedrock<br>Soil characteristics consistent with pollution control objectives<br>Suitability of site materials for use in construction |

S = wetland storage at beginning of calculation period
O = surface outflow
E = evapotranspiration
R = ground-water recharge

All units are expressed in terms of volume or water depth over the wetland surface.

The water balance should be estimated during site selection and checked after preliminary design. In areas with pronounced seasonal drought (e.g., most of the western United States), the calculation should definitely be performed for this period. Ground-water terms are difficult to establish with assurance, but they should at least be estimated as closely as possible by a hydrogeologist familiar with the location. As demonstrated by the fact that natural wetlands often dry below the soil surface, permanent standing water is not required for a wetland to be viable. Research on natural wetlands in Washington State has found that plant community richness declines substantially when drying extends longer than 2 months, compared to wetlands with shorter dry periods (9). Hence, the water balance should at least demonstrate that drying will never extend longer than 2 months.

Brodie (8) and Mitsch (10) have discussed positioning constructed wetlands in watersheds. Brodie (8) listed advantages and disadvantages of locating wetlands in upper reaches, on slopes, and in lowlands. No single setting is clearly optimal; thus, location from this standpoint depends on project objectives and the relative importance of the advantages and disadvantages at the specific site under consideration. Some possibilities for locating constructed wetlands in the overall landscape include:

- Just off stream channels, for baseflow supply by diversion.
- In stream floodplains, separated from the low-flow channel by a natural levee, with periodic water supplied to the wetland when the levee is topped.
- Several small wetlands in upper reaches of the watershed.
- One large wetland in lower reaches.
- Several small wetlands in lower reaches.
- Terracing into the landscape in steep terrain.

Constructing several small wetlands in the upper watershed provides some advantages relative to locating one large wetland in the lower reaches, such as better survival of extreme events, closer proximity to pollutant sources, and local flood protection. In contrast, the single large lowland wetland can provide overall greater flood reduction capability, if that is an objective. An alternative is the multiple lowland wetland plan, under which each can take a portion of high flows with less vulnerability to any one.

## *Sizing Constructed Wetlands*

### Establishing Volume

Possible arrangements of a constructed wetland in relation to runoff quantity and quality control requirements are:

- Place a runoff quantity control device “on line” and a constructed wetland “off line” to treat all runoff up to a certain volume.
- Construct a wetland with a permanent pool (“dead storage”) zone for treatment and a “live storage” zone and discharge control sized for peak runoff rate control.
- Construct a wetland only for treatment (for situations where quantity control is not required).

The first arrangement takes advantage of the fact that most of the pollutant mass loading over time is transported by runoff from the more frequent, smaller storms and the “first flush” from the less frequent, larger storms. This is the recommended arrangement where runoff quantity control is required because 1) the relatively shallow depths needed to maintain wetlands are somewhat inconsistent with the large storage volume needed for quantity control and 2) large surges of water can damage the wetland.

Basic sizing decisions involve the dead storage volume, surface area, depth contouring, and live storage volume, if runoff quantity control will be provided. There are three fundamental ways to calculate the treatment volume of a constructed wetland:

- Compute the volume needed to provide the required HRT for achieving a desired effluent concentration of the limiting pollutant (the hardest to remove), given a certain influent concentration, by using a mechanistic equation.
- Compute according to maximum allowable loading rates of water or specific pollutants established empirically from measurements on operating systems.
- Compute on the basis of a hydrologic criterion.

The first two approaches are employed in municipal and mining industry wastewater applications, where parameterized mechanistic equations or allowable loading rates exist for BOD and nitrogen in sewage and iron and manganese in mining effluents (6). Similar relationships do not exist for stormwater and will be difficult to develop, given the variability of flows and pollutant concentrations.

Therefore, stormwater wetland sizing must be determined using some form of the third approach. One version calls for choosing a volume sufficient to hold all runoff from a set percentage of the annual storms (e.g., 90 percent) or to hold a set depth of runoff generated by the contributing catchment (e.g., the first 2.5 cm = 1 in.). Schueler (4) presents several sizing rules of this type. Equivalent to this version is an approach for using a “water quality design storm” of a selected recurrence frequency and duration. The Washington State Department of Ecology (11) has taken this approach, selecting the 6-month, 24-hour rainfall event, which in Seattle is approximately equivalent to the first 3 cm of runoff, for stormwater treatment design in the Puget Sound basin.

A third version of the hydrologic basis is the method developed from wet pond performance data collected during the Nationwide Urban Runoff Program by the U.S. Environmental Protection Agency (EPA) (12). Using this method implicitly assumes that constructed wetlands will perform at least as well as wet ponds of equivalent treatment volume, which seems to be a safe assumption given the treatment advantages offered by a more structurally complex, vegetated system. The data exhibited an association between treatment efficiency and the ratio of permanent pool volume to runoff volume associated with the mean storm, termed the “volume ratio.” The mean storm is the average rainfall quantity over all storms in a long-term record at a gaging station. TSS loading reduction is typically around 75 percent at a volume ratio of 2.5, which is a common design basis. Obtaining increasingly better performance levels requires exponentially increasing basin size because the contaminants hardest to capture are those still in suspension or solution.

With this means of sizing constructed wetlands, the task almost entirely involves hydrologic analysis. This is another point at which hydrologic expertise is important to the design effort. Unless actual data are available from gaging the catchment that will contribute to the constructed wetland, the hydrologic analysis must be performed using a model. Modeling options include, in order of preference, a well-calibrated continuous simulation computer model, such as EPA’s SWMM and HSPF, an event-based model such as the Soil Conservation Service’s curve number method, and, where adequate data exist, a locally derived empirical model of the rational method type.

Once the hydrologic analysis is complete, the permanent pool volume (VP) calculation can be made very simply by using the equation:

$$VP = C * VR * AC$$

where

C = unit conversion factor
VR = runoff volume from hydrologic analysis
AC = contributing catchment area

Schueler (4) recommended a minimum VP of 1.6 cm/ha of contributing catchment area, which will increase the wetland size over that calculated by the equation in small catchments.

This procedure is used for general runoff pollution control purposes. Knowledge is inadequate at present to perform detailed sizing calculations for such specific purposes as control of metals and nutrients. These special objectives can be advanced in part by installing appropriate design features (addressed later in this paper). It is known that the maximum potential to remove dissolved pollutants, which include certain nitrogen and phosphorus forms and some metals, is reached with a long HRT in the dead storage (2 to 3 weeks) (13, 14). The average residence time can be checked as follows: 1) perform the hydrologic analysis to determine the rate of flow to the wetland associated with the mean storm (Q), and 2) calculate HRT = VP/Q. If HRT is less than 2 to 3 weeks and dissolved pollutant removal is an objective, increase VP to obtain HRT in that range.

If the wetland has live storage for peak runoff rate control, the volume of that zone and the discharge orifice size will also have to be calculated. These calculations require hydrograph simulation and routing analysis and are beyond the scope of this paper. They should be performed by a qualified hydrologist.

**Permanent Pool Surface Area and Depth Contouring**

A larger surface area for the same volume provides better treatment by allowing more light penetration for photosynthetic activity by plants and algae, more aeration for aerobic chemical and biological processes, and a shorter settling distance for particles. A straightforward way of establishing the wetland surface area (AW) is to start by selecting a trial mean depth (D) from the following approximate ranges (after Schueler [4]):

| | |
|---|---|
| Shallow marsh: | 0.30 to 0.45 m |
| Pond/marsh: | 0.60 to 0.85 m |
| Extended-detention wetland: | 0.25 to 0.30 m (permanent pool)<br>1.0 m (extended-detention zone) |
| Pocket wetland: | 0.15 to 0.40 m |

Using the trial mean depth, calculate surface area by AW = VP/D. Determine the wetland to contributing catchment area ratio (AW/AC), and compare it with the guidelines in Table 3.

Once satisfactory basic dimensions are determined, allocate depths to the different wetland zones according to the design concept. Schueler (4) recommended the following zones to obtain diversity in structure and treatment capabilities:

- Deep areas (30 to 180 cm deep, no emergent vegetation)—forebay, micropools, deep water pools, and channels.
- Low marsh (15 to 30 cm below normal pool).
- High marsh (0 to 15 cm below normal pool).
- Irregularly inundated zone (above normal pool).

Schueler went on to supply approximate depth allocations for the various zones and design concepts, and the reader is referred to his guidelines for these details. For example, he recommended allocating 40 percent of the surface area to the high marsh and 40 percent to the low marsh in the shallow marsh design, with 5 percent each given to the forebay, micropools, deep water, and irregularly inundated zones.

### *Recommended Constructed Wetland Design Features*

Adequate size is a necessary but not sufficient condition for good treatment performance. The theoretical HRT provided by the volume will not be achieved in practice if the layout permits water to traverse the wetland faster. Many of the features presented in this section are recommended to reduce the tendency of flow to short-circuit the wetland and fail to achieve an actual HRT as long as the theoretical HRT. Given that natural wetlands generally exhibit the recommended features, the selected reference system(s) should be employed as a model for designing these features. The recommendations are presented here in an abbreviated list format; consult the comprehensive sources referenced earlier for more detail.

**Shaping the Wetland**

Create a complex microtopography to lengthen the edge and flow path by using high marsh peninsulas and islands. Create at least two distinct cells by restricting the flow to a narrow passageway using the following features:

- Make the wetland relatively wide at the inlet to facilitate distribution of the flow well.
- Maximize the distance between the inlet and outlet.

The effective length to width ratio should be 5:1, preferably, and at least 3:1.

**Slopes**

The longitudinal slope (parallel to the flow path) should be less than 1 percent.

The wetland should be carefully constructed to have no lateral slope (perpendicular to the flow path) to avoid concentration of the flow in preferred channels, which reduces actual HRT and risks erosion.

Side slopes should be gradual (e.g., 5:1 to 12:1 horizontal to vertical), as in natural wetlands. Nowhere should the side slope be greater than 3:1.

**Forebay**

A forebay is a relatively deep zone placed where influent water discharges. It traps coarse sediments, reduces incoming velocity, and helps to distribute runoff evenly over the marsh.

Install a forebay in shallow marsh and extended-detention wetlands. In the case of a pond/marsh system, the pond serves this purpose. The restricted size of pocket wetlands generally does not allow for a forebay. Make the forebay 1.2 to 1.8 m deep. The forebay should be a separate cell set aside by high marsh features.

Provide maintenance access for heavy equipment (4.5 m wide and a maximum 5:1 slope) directly to the forebay. The forebay bed should be hardened to prevent disturbance during cleanout.

### Flow Channeling

Create sheet flow to the maximum extent possible. Where flow must be channeled, use multiple, meandering channels rather than a single straight one. Intersperse open water areas with marsh, rather than connecting along the flow path. Minimize velocity in channels to prevent erosion and expand habitat opportunities.

### Outlet Design

Place a micropool 1.2 to 1.8 m deep at the outlet. Install a reverse-sloped pipe 30 cm below the permanent pool elevation. This outlet design has been found to avoid clogging, to which constructed wetland outlets are prone (4).

Install a drain capable of dewatering the wetland in 24 hours to allow for maintenance. Control the drain with a lockable, adjustable gate valve. Place an upward-facing, inverted elbow on the end of the drain to extend above the bottom sediments.

### Soils

Medium-fine textures, such as loams and silt loams, are optimal for establishing plants, capturing pollutants, retaining surface water, and permitting ground-water discharge. Circumneutral pH (approximately 6 to 8) is best for supporting microorganisms, insects, and other aquatic animals.

A relatively high content of highly decomposed organics ("muck") is favorable for plant and microorganism growth and the adsorption of metals and organic pollutants. Muck soils are preferred to peats (less decomposed organics), which tend to produce somewhat acidic conditions, to be low in plant nutrients, and to offer relatively poor anchoring support to plants.

Vegetation becomes established more quickly and effectively in constructed wetlands when soils contain seed banks or rhizomes of obligate and facultative wetland plants. Attempt to obtain any available soils that offer these resources.

Soil characteristics recommended for specific pollution control objectives are:

- High cation exchange capacity—for control of metals.
- High exchangeable aluminum and/or iron—for control of phosphorus.

### Liner

An impermeable liner is required when infiltration is too rapid to sustain permanent soil saturation, when there is a substantial potential of ground water being contaminated by percolating stormwater, or both. Infiltration losses are insignificant at most sites with Soil Conservation Service Class B, C, and D soils. Also, sediment deposition is likely to seal the bottoms of constructed wetlands. Generally, therefore, a liner is likely to be needed only in Class A soils.

### Emergency Spillway

An emergency spillway is required when the wetland will be used for runoff quantity control (and any other situation in which it would be possible for runoff to enter from a larger storm than the largest storm the facility is sized to handle).

### Buffer

A buffer should be provided around the wetland both to separate the treatment area from the human community and, if development habitat is an objective, to reduce the exposure of animals to light, humans, and pets. The buffer requirement can be waived for pocket wetlands without wildlife habitat objectives and adjacent structures. The minimum buffer width should be 8 m, measured from the maximum water surface elevation, plus 5 m to the nearest structure. The buffer should be increased to at least 16 m when developing wildlife habitat is an objective. It should be sloped no more than 5:1 (horizontal to vertical).

Preserve existing forest in the buffer area if at all possible. At least 75 percent of the buffer should be forested to avoid attracting geese and to provide better protection and habitat for other wildlife.

### Pretreatment

The constructed wetland is expected to serve as the primary treatment device. Nevertheless, some pretreatment can prevent problems in the wetland, produce a more self-sustaining system, and increase the potential for ancillary benefits. Pretreatment mechanisms that should be considered include:

- Catch basins, for trapping the largest solids.
- A presettling basin or biofilter, when the watershed produces relatively high solids loadings.
- Oil-water separators.

## *Designing for Ancillary Benefits and Avoidance of Problems*

### Ancillary Benefits

Potential ancillary benefits of constructed wetlands include:

- Wildlife habitat.
- Aquaculture for harvest.
- Primary production for food-chain support.

- Biological diversity.
- Open space for recreational, educational, and other human uses.

This paper focuses on creating wildlife habitat, which also helps achieve the latter three benefits. The preceding recommendations on configuring the wetland were also designed in part to contribute to these benefits.

An issue, of course, is the attraction of wildlife to a wastewater treatment area that might be contaminated. It is thought, but not proven, that levels of contamination hazardous to wildlife are a relatively rare problem restricted to watersheds with very high vehicle traffic, proportions of impervious surface, and/or population densities. It is also thought that such problems can be addressed at least partially by reversing the recommendations to attract wildlife; that is, install features that discourage wildlife colonization. In either case, a qualified wildlife biologist is needed to design the features. For now, the best course seems to be using and studying constructed wetlands for many applications, but avoiding their use in areas with a high potential for toxic contamination.

The main factor in designing for wildlife habitat is complex structure that provides a variety of possible niches to support feeding, nesting, breeding, and refuge requirements of desired species. Fortunately, many features that promote pollution control also enhance wildlife habitat. Figure 3 illustrates several suggested features for habitat development, and the comprehensive references provide other illustrations.

Following is a summary of features that enhance wildlife habitat drawn from Figure 3 and the references:

- Irregular shorelines.
- A wide range of depth zones—deep zones provide habitat for invertebrates, amphibians, and possibly fish; higher marsh areas offer feeding grounds to birds; and various nesting opportunities are provided in the different zones.
- Perimeter forest buffer at least 16 m wide.
- Connect wetland to corridors (e.g., streams and passages to forests and other wetlands) that allow wildlife movement.
- Increase wetland size if very small—research has shown that wildlife use is not strongly correlated to the size of natural wetlands of 0.5 to several hectares in area (15), but is low in very small natural and constructed wetlands (less than 0.1 hectares).
- Select plants that offer refuge, nesting, feeding, and breeding habitat.
- Install other features providing for nesting and refuge, such as:
  - Islands (protection for ground-nesters) (minimum 3 $m^2$ for a waterfowl pair, above maximum water surface elevation, densely vegetated, positively drained).

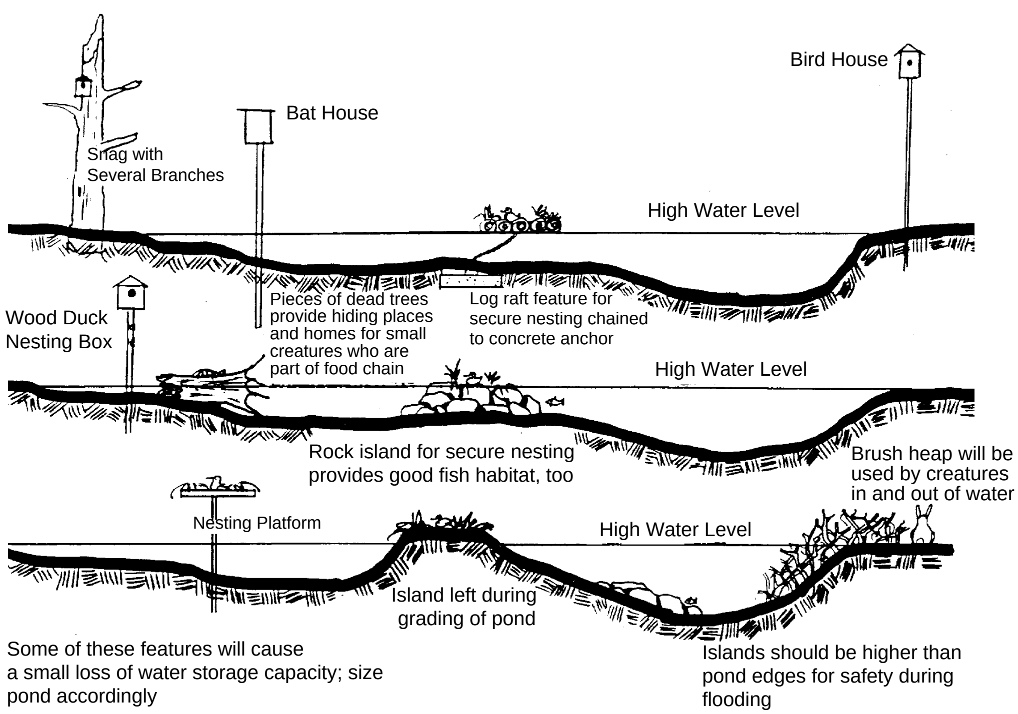


**Figure 3. Suggested constructed wetland habitat features (11).**

- Snags (dead tree trunks installed for cavity-nesters).
- Nest boxes and platforms (unique designs for cavity-nesters).
- Buffer trees (for foliage-nesters).
- Logs, stumps, and brush (for bird perches and small-mammal refuge).

• Avoiding significant water level fluctuations—this is an inherent disadvantage of stormwater wetlands relative to wildlife. The best remedy is to precede the wetland with runoff quantity control. Otherwise, the configuring recommendations stated earlier provide the best situation obtainable in stormwater applications.

**Avoidance of Problems**

Potential problems associated with constructed wetlands include:

- Mosquito breeding.
- Aesthetic drawbacks.
- Safety concerns.
- Attraction of geese and ducks, which can constitute a nuisance.
- Development of a monoculture of undesirable vegetation.
- Accumulation of toxicants.

The extent of actual occurrence of these problems and managing to avoid or minimize them is addressed briefly in this paper.

Mosquitoes are actually rarely a problem in well-designed and operated constructed wetlands; thus, education of the concerned public is part of the solution. A problem with mosquitoes can best be prevented by providing diverse habitats that support predatory insects. Mosquito fish *(Gambusia)* have been used successfully to control mosquitoes in permanent ponds, but the introduction of the fish in areas to which they are not native must be carefully assessed.

Aesthetic problems can be avoided with careful attention to construction and vegetation establishment. The buffer and tall emergent vegetation can be used to conceal such wetland characteristics as water level fluctuation and films on the water.

Constructed wetlands are inherently safer than deeper ponds, but some degree of potential hazard to children is associated with deep zones. Hazards can be avoided by establishing gradual side slopes and a shallow marsh safety bench (5 m wide) where the toe of the side slope meets any deep pool, by concealing outlet piping, and by providing lockable access. In general, fencing should only be needed on the embankment above large outfalls, where they exist.

Nuisance waterfowl can be discouraged in several ways. Maintain the buffer largely with forestland (at least 75 percent), and avoid the growth of turf grass around the wetland. Also, maintain a variety of depths, especially high marsh not favored by geese and mallards. Another important measure is to educate citizens and place signs to discourage feeding.

The tendency for wetlands to develop undesirable plant monocultures can be limited by maintaining structural diversity and a range of depths, especially shallower areas. A diverse selection of native flora should be planted shortly after the wetland is constructed.

Regarding toxicant accumulations, evidence suggests that metals and organics are tightly bound in sediments and do not tend to become mobilized over long periods. When maintenance is performed, disposal of spoils becomes an issue. Current knowledge indicates that spoils pass hazardous waste tests and can be safely land applied or landfilled (4). Plan an onsite application area if possible to save costs of disposal.

## *Vegetation Selection and Establishment*

As experience with wetland creation, restoration, and construction projects accumulates, it is becoming increasingly clear that the plant community develops best when the soils harbor substantial vegetative roots, rhizomes, and seed banks. Its development is also enhanced by the opportunity for volunteer species to enter from nearby donor sites; however, volunteers cannot be relied on for vegetation establishment. Transplants may be supplanted by more vigorous resident and volunteer stock under these circumstances and may actually constitute a minor component of the eventual community. Nevertheless, transplanting is generally a wise strategy, and most of the specific guidance available for establishing wetlands concerns this source; thus, it is fully covered below.

Hydric soils containing vegetative plant material collected for establishing new wetlands are becoming known as “wetland mulch.” It appears that ample use of this mulch enhances diversity and the speed of vegetation establishment, but the mulch content is somewhat unpredictable and donor sites are limited. Also, guidelines for extracting, handling, and storing the material are limited. A danger with the use of mulch is the possible presence of exotic, opportunistic species that will out-compete more desirable natives. Therefore, at least the donor sites that obviously support such plant species should be avoided in obtaining material. Preferred donor material includes wetland soils removed during maintenance of highway ditches, swales, sedimentation ponds, retention/detention ponds, and clogged infiltration basins and during dredging, or from natural wetlands that are going to be filled under permit (although these soils are best used for mitigating the loss). It is recommended that the upper 15 cm of donor soils be obtained at the end of the growing season, if possible. The best way to hold soils until installation is somewhat uncertain but must include keeping soils moist in conditions that will maintain vital dormancy. Efforts are under way to establish repositories for mulch reclaimed in maintenance operations.

The reliability of transplanting and the instant partial cover it provides make it necessary regardless of the potentials offered by wetland mulch and volunteer species recruitment. Commercial wetland plant nurseries now operate in many places in the nation to provide material. The following list of general vegetation selection principles was compiled from Garbisch's (16) recommendations for creating wetlands and from the comprehensive constructed wetland works:

- Base selections more on the prospects for successful establishment than on specific pollutant uptake capabilities (plant uptake is a highly important mechanism only for nutrients, much of which are released upon the plant's death; nutrient removal is more the result of chemical and microbial processes than of plant uptake).
- Select native species, and generally avoid natives that invade vigorously.
- Use a minimum of species adaptable to the various elevation zones; diversification will occur naturally.
- Select mostly perennial species, and give priority to those that establish rapidly.
- Select species that are adaptable to the broadest ranges of depth, frequency, and duration of inundation (hydroperiod).
- Match the environmental requirements of plant selections to the conditions to be offered by the site. Consider especially hydroperiod and light requirements.
- Give priority to species that have been used successfully in constructed wetlands in the past and to commercially available species.
- Avoid specifying only species that are foraged by wildlife expected to utilize the site.
- Phase the establishment of woody species to follow herbaceous ones.
- Consider planting needs to achieve designated objectives other than pollution control.

Although excessive emphasis on vegetation selection based on pollution control capabilities should be avoided, considerable information on that subject has been compiled. Kulzer (17) prepared a summary of the demonstrated capabilities of plants for the various common classes of pollutants. The most versatile genera that have species representatives in most parts of the nation are *Carex, Scirpus, Juncus, Lemna,* and *Typha.*

Schueler (4) and Garbisch (16) have assembled a considerable amount of specific guidance on the construction and vegetation establishment process for constructed wetlands and created wetlands, respectively. The course manual by Horner (5) also incorporates this guidance. Given the available literature, these topics are not addressed in this paper.

### Operating Constructed Wetlands

Relative to retention/detention ponds, constructed wetlands pose a relatively significant routine operating burden. Operated properly, however, they should not require periodic expensive sediment cleanouts. From the outset, the project should include a formal operation and maintenance plan that covers the following elements: 1) inspection, 2) sediment management, 3) water management, and 4) vegetation management.

There are two levels of inspection: routine and comprehensive. Rapid, routine inspections should be made by a qualified observer to identify and take action on any problems that would damage the wetland's function. Recommended scheduling for these inspections is monthly and after each storm totaling more than 1.25 cm (0.5 in.) of precipitation. Comprehensive inspections should take place twice yearly the first 3 years, once in the growing season and again in the nongrowing season. Conditions that should be noted during these inspections include:

- Dominant plants and their distributions in each zone.
- Relative presence of intentionally planted and volunteer invasive and noninvasive species.
- Plant condition—look for signs of disease (yellowing, browning, wilting), pest infestations, and stunted growth.
- Depth zones and microtopographic features compared with the original plan.
- Normal pool elevation compared with the original plan.
- Sediment accumulations (locations and approximate quantities).
- Outlet clogging.
- Buffer condition.

The objective of sediment management is to trap—and when necessary remove—sediments before they reach the shallow zones. Forebays will probably have to be drained and dredged every 2 to 5 years. The pond in a pond/marsh system is, in part, a large forebay and should not need dredging as frequently.

If water levels do no conform to plans, or there is another reason to change them, regulation can be accomplished by installing a flash board at the desired height at the outlet weir or by adjusting the gate valves (if provided). Remove clogging debris from around the outlet as necessary.

In vegetation management, provide extra care during the first 3 years to plantings, especially trees, including watering, supporting, mulching, and removing weeds. Reinforcement plantings will probably be required after 1 or 2 years and should be added as necessary. Manually remove undesirable species with a high potential to invade and dominate, if they will subvert achievement of the designated objectives. Cut or dig out woody, unwanted species in marsh zones before they cause damage and become too difficult to remove.

Harvesting the wetland for nutrient control can be performed but has many drawbacks, including cost, disposal, and damage to the system. It is generally only possible to cut aboveground biomass, which will not adequately control the release of nutrients.

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# *Stormwater Pond and Wetland Options for Stormwater Quality Control*

**Thomas R. Schueler**
**Metropolitan Washington Council of Governments, Washington, DC**

## Abstract

In this paper, 10 designs for stormwater wetland and pond systems used for effective urban runoff quality control are surveyed. Each design is based on a different allocation of deep-pool, marsh, and extended detention storage. The comparative pollutant removal capability of the 10 designs are reviewed based on a national survey of 58 performance monitoring studies. In addition, the reported longevity, maintenance requirements, and environmental constraints of each design is assessed.

A team approach for selecting the most appropriate design at the individual development site is strongly recommended. Key selection factors, such as space, drainage area, and permitability, are discussed. A seven-stage design/construction process is outlined to ensure the team selects and builds the most appropriate and effective design.

The paper points out that the uncertain regulatory status of pond/wetland systems should be resolved so that this effective runoff control technology can be appropriately used.

## Introduction

The use of stormwater ponds to control the quality of urban stormwater runoff has become more widespread in recent years. At the same time, designs have become more sophisticated to meet many environmental objectives at the development site. Today, the term stormwater pond can refer to any design alternatives in a continuum that allocates different portions of runoff treatment volume to deep pools, shallow wetland areas, and temporary extended detention storage. This paper provides a broad review of the comparative capabilities of pond and wetland systems.

In an operational sense, these systems can be classified into one of ten categories:

1. Conventional dry ponds (quantity control only)
2. Dry extended detention (ED) ponds
3. Micropool dry ED ponds
4. Wet ponds
5. Wet ED ponds
6. Shallow marsh systems
7. ED wetlands
8. Pocket wetlands
9. Pocket ponds
10. Pond/marsh systems

**Table 1. Comparative Storage Allocations for the 10 Stormwater Pond/Wetland Options (% of Total Treatment Volume)**

| Pond/Wetland Alternative | Deep Pool | Marsh | ED |
|---|---|---|---|
| 1. Conventional dry ponds (quantity control only) | 0 | 0 | 0 |
| 2. Dry ED ponds | 0 | 10 (ls) | 90 |
| 3. Micropool dry ED ponds | 30 (f, m) | 0 | 70 |
| 4. Wet ponds | 80 | 20 (b) | 0 |
| 5. Wet ED ponds | 50 | 10 (b) | 40 |
| 6. Shallow marsh systems | 40 (f, m, c) | 60 | 0 |
| 7. ED wetlands | 20 (f, m) | 30 | 50 |
| 8. Pocket wetlands | 20 (f) | 80 | 0 |
| 9. Pocket ponds | 80 | 20 (b) | 0 |
| 10. Pond/marsh systems | 70 | 30 (b, m) | 0 |

Note: The storage allocations shown are approximate targets only.
ls = lower stage of ED pond often assumes marsh characteristics
f = forebay
m = micropool
c = channels
b = aquatic bench

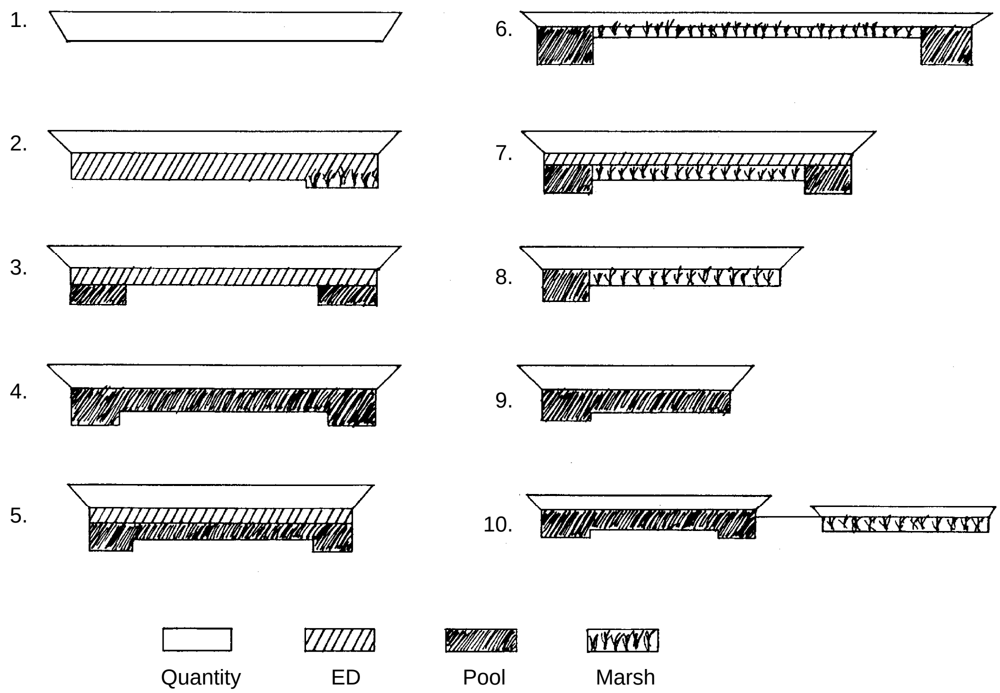


**Figure 1. Stormwater pond options.**

Each of these designs (shown in cross-sectional view in Figure 1) can be distinguished by how it allocates the total treatment volume to deep pools, shallow wetlands, and temporary extended detention storage. As can be seen, most designs incorporate two and sometimes three runoff treatment pathways. Comparative storage allocations are shown in quantitative terms in Table 1. It is important to note that these allocation targets are approximate and relative, and individual systems may not always conform to the target.

Stormwater pond systems can also be configured in many different ways, as shown in Figure 2. Ponds can be located "on-line" or "off-line" and can be arranged in multiple cells. On-line ponds are located directly on streams or drainage channels. Off-line ponds are constructed away from the stream corridor. Runoff flow is split from the stream and diverted into off-line ponds by a flow splitter or smart box.

The total treatment volume need not be provided within only one cell. Stormwater ponds can contain multiple storage cells, and these often enhance the performance, longevity, and redundancy of the entire system.

All pond designs provide additional storage to control the increased quantity of stormwater produced as a consequence of urban development. This "quantity control" storage is usually defined as the storage needed to keep postdevelopment peak discharge rates equivalent to predevelopment levels for the 2-year storm. The quantity control storage is in addition to, and literally on top of, the quality control runoff storage.

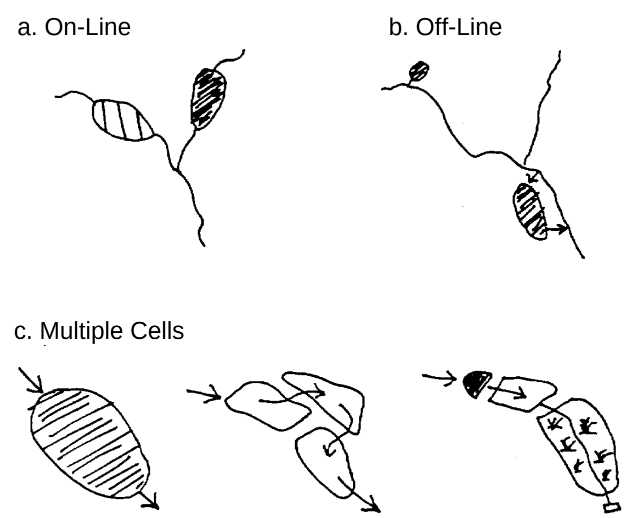


**Figure 2. Stormwater pond configurations.**

## Comparative Pollutant Removal of Stormwater Pond Designs

Each of the three basic treatment volume allocations (pool, marsh, and ED) use different pollutant removal pathways. Therefore, it is not surprising to find considerable variability in the projected removal rates for each of the 10 stormwater pond designs (Table 2). The table is based

Table 2. **Comparative Pollutant Removal Capability of Stormwater Pond/Wetland Alternatives**

| | Pollutant Removal Rate | | | |
|---|---|---|---|---|
| **Pond/Wetland Alternative** | **TSS** | **TP** | **TN** | **Reliability** |
| 1. Conventional dry ponds | 10 | 0 | 0 | Moderate |
| 2. Dry ED ponds | 30 | 10 | 10 | Low |
| 3. Micropool dry ED ponds | 70 | 30 | 15 | Moderate (projected) |
| 4. Wet ponds | 70 | 60 | 40 | High |
| 5. Wet ED ponds | 75 | 65 | 40 | High |
| 6. Shallow marsh systems | 75 | 45 | 25 | High |
| 7. ED wetlands | 70 | 40 | 20 | Moderate |
| 8. Pocket wetlands | 60 | 25 | 15 | Moderate (projected) |
| 9. Pocket ponds | 60 | 30 | 20 | Moderate (projected) |
| 10. Pond/marsh systems | 80 | 70 | 45 | High |

TSS = total suspended solids
TP = total phosphorus
TN = total nitrogen

on a review of 58 pond and wetland performance studies conducted across the United States and Canada (1).

While seven of the ten pond designs have been monitored in the field, the performance of three designs (pocket ponds, pocket wetlands, and micropool dry ED ponds) can only be projected based on design inferences and field experience.

Two of the pond designs possess limited capability to remove pollutants—the conventional dry pond and the dry ED pond. These pond systems seldom have been observed to reliably remove sediment and have shown virtually no capability to remove nutrients. The performance of dry ED ponds is expected to improve if micropools are added at the inlet and the outlet. Micropools help to pretreat incoming runoff, prevent resuspension, and reduce clogging.

When properly sized and designed, wet ponds can reliably remove sediments and nutrients at relatively high rates. The deep pool of the wet pond allows for gravitational settling. Removal rates for wet ponds can be incrementally improved if the deep pool is combined with extended detention, as in the wet ED pond system.

The removal capability of wetland systems (designs 6, 7, and 8) is generally comparable to that of wet ponds of similar size. Sediment removal often is slightly higher in wetland systems, but nutrient removal appears to be somewhat lower and less reliable. Shallow marsh systems exhibit slightly higher removal rates than either the ED wetland or the pocket wetland systems, which may be explained by the greater surface area and complexity of shallow marsh systems (2).

Ponds and wetlands that do not have a reliable source of base flow, and that have a water level that frequently fluctuates, are termed pocket ponds and wetlands. These systems typically serve very small drainage areas and are excavated to the local water table. Consequently, pocket facilities are often less than a quarter acre in size and possess few of the design features of their larger counterparts. Therefore, pocket wetlands are thought to have lower pollutant removal capability, especially for nutrients.

Pond-marsh systems appear to possess the greatest overall pollutant removal capability of all the designs monitored. The permanent pool and the shallow wetland provide complementary and redundant removal pathways, and reduce remobilization of pollutants.

It should be noted that while differences in removal capability do exist among the 10 designs, other key design factors also must be present if these rates are to be achieved. First, the system must be capable of capturing at least 90 percent of the annual runoff volume delivered. Second, incoming runoff must be pretreated in a forebay or deep pool. Third, the system must meet minimum criteria for internal geometry (flow path, microtopography, surface-area-to-volume ratio). Clearly, a poorly conceived or designed pond system will not achieve the rates shown in Table 2.

## Comparative Ability To Protect Downstream Channels

Pond systems that combine ED storage with stormwater quantity storage appear to provide the best measure of protection for downstream channels exposed to the erosive potential of bankfull and subbankfull floods. Recent field research has demonstrated that control of the 2-year storm quantity exacerbates, rather than reduces, downstream channel erosion problems. Modeling studies suggest that extended detention (e.g., 6 to 24 hours) of relatively small treatment volumes may have some potential to alleviate downstream channel erosion problems. Additional field research is needed to confirm the value of ED in protecting channels.

## Comparative Physical, Environmental, and Maintenance Constraints

Each of the 10 pond systems are subject to many different constraints that may limit their use at a particular site. Some of the more common constraints are outlined in Table 3.

Physical constraints include available space, climate, dry weather base flow, and contributing drainage area. Maintenance constraints may involve susceptibility to clogging and the frequency and difficulty of sediment cleanout.

**Table 3. Comparative Capability of 10 Pond/Wetland Alternatives—Physical, Environmental, and Maintenance Constraints**

| Pond/Wetland Alternative | Minimum Drainage Area[a] | Space Index[b] | Water Balance | Clogging Risk | Sediment Cleanout | Waters of U.S. (404) | Stream Warming | Safety Risk |
|---|---|---|---|---|---|---|---|---|
| 1. Conventional dry ponds | 5 | 0.5 | No restrictions | Moderate | Basin (10-20 yr) | ? | Low | Low |
| 2. Dry ED ponds | 10 | 1.0 | No restrictions | High | Basin (10-20 yr) | Yes | Moderate | Low |
| 3. Micropool dry ED ponds | 15 | 1.0 | May require base flow | Low | Forebay (2-5 yr) | Yes | Moderate | Low |
| 4. Wet ponds | 25+ | 1.0 | Climate | Low | Forebay (2-5 yr) | Yes | High | High |
| 5. Wet ED ponds | 25+ | 1.0 | Climate | Low | Forebay (2-5 yr) | Yes | High | High |
| 6. Shallow marsh systems | 25+ | 2.5 | Climate, base flow | Low | Forebay (2-5 yr) | Yes | High | Moderate |
| 7. ED wetlands | 10+ | 1.5 | Climate, base flow | Low | Forebay (2-5 yr) | ? | High | Moderate |
| 8. Pocket wetlands | 1-5 | 2.0 | Climate, ground water | Moderate | Basin (5-10 yr) | No | Moderate | Moderate |
| 9. Pocket ponds | 1-5 | 1.0 | Climate, ground water | Moderate | Basin (5-10 yr) | No | Moderate | Moderate |
| 10. Pond/marsh systems | 25+ | 1.5 | Climate, base flow | Low | Pool (10-15 yr) | Yes | High | High |

[a]Maximum of 400 acres in most cases.
[b]Space consumption index (1 = space required for wet pond).

Perhaps the most restrictive constraints, however, are of an environmental nature. Recent research has indicated that on-line pond and wetland systems can have serious impacts on the local and downstream environment, if they are not properly located and designed (2). The most serious include the modification or destruction of high-quality forests and wetlands as a consequence of construction, and downstream warming. Consequently, the siting of ponds and wetlands in the mid-Atlantic region has become a major focus of federal and state regulatory agencies. Presently, both a Section 404 (wetlands) and a Section 401 water quality certification permit must be obtained for the construction of any on-line stormwater pond or wetland.

## A Team Approach for Selecting the Most Appropriate System

Selecting and designing a pond system has become a complex and lengthy process. An effective approach is to assemble a design team consisting of a stormwater engineer, landscape architect, environmental consultant, and the construction contractor. The combined expertise of the design team, along with early and frequent coordination with local plan reviewers, is an essential ingredient for implementing the most appropriate system for the development site and the downstream community.

The design team works together throughout the planning, design, approval, and construction process, which can take as long as 2 years. Building an effective and appropriate pond system consists of seven general steps, as outlined below:

### *1. Evaluation of the Feasibility of the Site*

The design team has two major tasks. The first task is to define, in consultation with local planning and resource protection agencies, the primary watershed protection objectives for the particular site and stream. The objectives may include specific targets for pollutant reduction, flood control, channel protection, wetland creation, habitat protection, protection of indicator species (e.g., trout), or preservation of stream corridors. Careful identification of realistic and achievable objectives early in the process is critical for allowing the design team to incorporate them into the design and construction process.

The second task is to analyze the physical and environmental features of the development site to determine if a pond system is feasible, appropriate, and can meet the primary watershed protection objectives. This typically involves a thorough delineation of the wetlands, forests, and catchments within the development, as well as the collection of geotechnical data to define soil properties and water balances. The design team also should assess both the site and downstream aquatic conditions during a site visit.

### 2. Development of the Initial Concept Plan

The task for the design team in this stage is threefold: 1) select the most appropriate pond design option, 2) identify the most environmentally suitable location for it, and 3) compute the size and geometry of the facility. The design team assembles a concept plan and then submits it to the local stormwater review agency and other regulatory agencies for preliminary review and approval. Early input from the permitting agencies is essential, and a joint field visit is often a useful means of securing it.

### 3. Development of the Final Design

In final design stage, the team adds engineering details to the concept plan and responds to the comments made by the local permitting authorities. The team works together to ensure that all standard pond design features are incorporated into the final design plans (e.g., benches, forebays, buffers, gate valves). (See Schueler [2] for a full list.) In addition, the plan should be thoroughly analyzed to reduce safety risks, allow for easy maintenance access, provide safe and environmentally sensitive conveyance to the pond, and reduce the future maintenance burden. The final plan is then submitted for review and approval by the appropriate local and state regulatory agencies.

### 4. Preparation of a Pondscaping Plan

This stage of the design process is critical but frequently overlooked. The design team jointly prepares an aquatic and terrestrial landscaping plan for the pond or wetland, known as a pondscape. It specifies the trees, shrubs, ground cover, and wetland plants that will be established to meet specific functional objectives within different moisture zones in and around the pond.

The pondscaping plan is more than a landscaping materials list, it also specifies necessary soil amendments, planting techniques, maintenance schedules, reinforcement plantings, and wildlife habitat elements needed to establish a dense and diverse pondscape over several growing seasons. Although landscape architects take the lead in the development of the pondscape, other members of the team can provide important contributions. For example, the engineer projects soil moisture zones, the contractor provides practical guidance on tree protection during construction and temporary stabilization, and the environmental consultant provides input on native wetland plants and propagation techniques.

### 5. Construction of the Pond

Appropriate designs only work when they are constructed properly. Therefore, it is essential to conduct a field meeting with the entire construction crew prior to construction. The design team outlines the purpose of the project, the sequence of construction activities, and walks through the no-disturbance limits. Short but regular meetings to inspect progress are helpful during the construction process, especially to modify decisions in the field. After construction is complete and the pond site is stabilized, the engineer performs an as-built survey for submission to local government authorities that verifies that the pond was constructed in accordance with the approved plans.

### 6. Establishment of the Pondscape

Establishing a functional pondscape requires frequent adjustment of the original pondscaping plan. Initially, the design team modifies the plan to account for actual moisture conditions and water elevations that exist after construction. The design team then reexamines the pondscape after the first growing season to determine if reinforcement plantings are needed.

### 7. Inspection and Operation of the Pond

The final stage of the process involves the final inspection of the facility, development of the maintenance practices and schedules, and the transfer of maintenance responsibilities to the responsible party.

## Resolving the Regulatory Status of Stormwater Ponds

Although pond and wetland systems are attractive options for urban nonpoint source control, their regulatory status has recently become very confused. This is due to the fact the these systems fall under the scope of three often conflicting sections of the Clean Water Act—Section 401 (water quality certification permits), Section 402 (stormwater National Pollutant Discharge Elimination System [NPDES] permits), and Section 404 (wetland permits). Confusion about these systems also stems from a number of particular factors:

First, pond systems often acquire wetland characteristics over time, whether by design or simply with age. At some point, they may become delineated wetlands, subject to the same protection and restrictions as natural wetlands. If a stormwater pond system does evolve into wetland status, then Section 404 wetland permits may be required and all future maintenance activities conducted on the stormwater pond system would likely require a permit. Conversely, it also is possible that a well-designed stormwater wetland would be eligible for a partial mitigation “credit” when it “evolves” into wetland status.

Second, most pond systems are located on waters of the United States (i.e., intermittent or perennial streams or drainage channels) and are thus subject to the Section 404 permit process, even when the system is not located within a delineated wetland. Some regulators have advocated that the prohibition against "instream treatment" should apply to stormwater pond systems, while others have required that an extensive alternatives analysis be undertaken before a permit is issued. In the former interpretation, the use of stormwater pond systems would be limited to off-line or pocket applications. Under the latter interpretation, the design team might have to demonstrate that all upland best management practice (BMP) alternatives are exhausted before a pond system can be constructed. While upland BMPs are an alternative, they do not possess the performance or longevity of pond and wetland systems and may not be adequate to protect streams or meet pollutant reduction targets.

Third, construction of stormwater ponds and wetlands within or adjacent to delineated natural wetlands can radically alter the characteristics of that wetland, either through excavation, fill, pooling, or inundation. In most cases, construction of stormwater ponds in natural wetland areas is strongly discouraged. In other cases, however, it may actually be desirable to convert degraded natural wetlands into stormwater wetlands. The conditions, if any, where these conversions might take place are the subject of considerable controversy. The influence of stormwater ponds on wetlands need not always be negative, however. In many cases, stormwater ponds can help protect downstream wetlands from degradation caused by uncontrolled stormwater flows and construction-stage sediment deposition.

Fourth, stormwater ponds have a dual nature: They can help to meet water quality standards in receiving waters, while at the same time contributing to possible violations of other standards. For example, ponds can help meet sediment, turbidity, nutrient, and toxics limits. At the same time, they may amplify the stream warming associated with urban development and thus lead to violations of temperature standards in some sensitive streams. This creates a great dilemma for regulators that must perform water quality certification on stormwater ponds.

The resolution of the uncertain and confusing regulatory issues relating to stormwater ponds is critical if application of this effective technology is to continue on a widespread basis. The challenge for designers will be to acknowledge and avoid the potential for negative environmental impact, whereas the challenge for the regulatory community will be to recognize the benefits of stormwater ponds and craft a regulatory policy that is practical rather than merely legal. Otherwise, the fifth member of the pond design team may have to be a lawyer. Hopefully, a workable policy can be developed in the near future that sets guidelines on the appropriate use of this effective nonpoint source control technology.

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# *Practical Aspects of Stormwater Pond Design in Sensitive Areas*

**Richard A. Claytor, Jr.**
**Loiederman Associates, Inc., Frederick, Maryland**

## Abstract

This paper's purpose is to provoke thought in establishing some considerations and techniques for the design of stormwater management ponds in sensitive areas, not to describe a step-by-step process for designing stormwater management ponds. The reader should have a basic understanding of the principles of small pond design, urban hydrology, water quality control, and best management practices.

First, practical design requires an inventory of the sensitive resources that need protection and an estimate of the project goals and potential environmental benefits. The next step is to develop a concept plan, which initiates the design process and ensures agency and public involvement in early stages of the project. Several techniques can be used to avoid or minimize negative impacts on sensitive areas, which this paper groups into techniques for either warm water or cool water environments. In addition, the paper covers three new theoretical techniques that combine warm water design practices with cool water mitigation approaches. Maintenance and monitoring issues are also discussed. Coupling a common sense approach with the need for innovative thinking should be a primary goal, and designers must factor into this challenge the goal of reaching a consensus with different interest groups.

## Goals and Expectations

Stormwater management ponds are often installed or constructed to fulfill regulations for the control of urban runoff. Controlling urban runoff usually means providing some kind of detention facility that controls the increased runoff frequency and volume in developing areas.

Good, practical stormwater management requires an assessment of what the pond needs to protect and an estimate of how well pond is likely to work. This involves conducting an inventory of existing natural and constructed features, which then becomes a basis for design considerations. For example, stormwater ponds often need to be located in the lower portion of a site to maximize the area and runoff draining toward them. This can create a conflict with existing, sensitive natural features, such as wetlands, seeps, springs, or even intermittent or perennial streams.

A natural resources inventory, which is essential for design, should at a minimum incorporate the following features:

- Topography
- Wetlands (including springs and seeps)
- Soils
- Floodplains
- Forest lands (vegetation)
- Watercourses
- Specimen trees
- Steep slopes, rock outcroppings, etc.
- Historical or archeological features
- Habitat

After a reasonably detailed natural resources inventory has been conducted, design should continue with an analysis of the receiving stream or ground-water aquifers. This may be very detailed and use various habitat analyses or biological indicators, or it can be a general overview. To pursue a sensitive design approach, however, establishing the type of aquatic resource fisheries (cold water versus warm water) is important.

After establishing the natural resources inventory and assessing what level of aquatic resource protection is warranted, a concept plan should be developed.

## Concept Plan Development

One of the most important elements in implementing a successful stormwater management plan is the development of a good concept plan. A concept plan allows various agencies and interest groups the opportunity to offer input at a time when change is reasonably inexpensive. Later in a program, change becomes much more difficult. Many resource protection agencies and special interest groups have conflicting goals, which should be resolved as much as possible in the early stages of the concept plan process so that meaningful projects ultimately become a reality.

One of the key elements of working in an environmentally sensitive area is compromise, but ingenuity is equally important. To advance technology and find different and possibly more successful methods of stormwater management pond design, new techniques should be proposed and implemented, even if unproven.

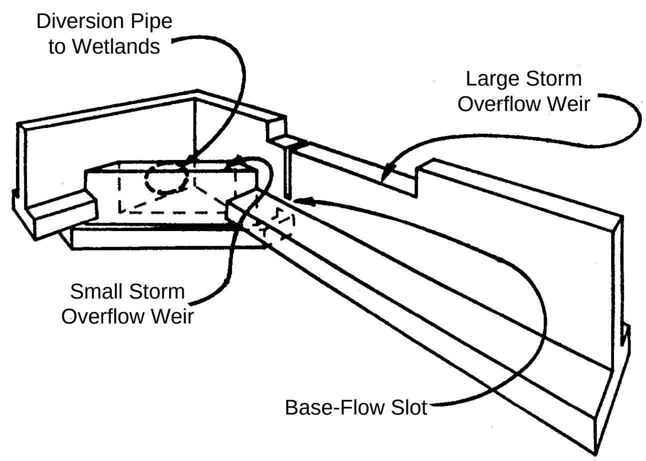


**Figure 1. Diversion structure or "flow splitter."**

## Techniques for Avoiding or Minimizing Impacts to Sensitive Areas

### *Warm Water Environments*

For warm water fisheries, where thermal impacts are not a major consideration, wet ponds (permanent pools of water) represent the most reliable and maintenance-free option for stormwater runoff quality control (1). Several techniques can enhance the pollutant removal efficiency of wet ponds and simultaneously minimize the impact that a large body of water has on surrounding sensitive areas. Some of these techniques are:

- Location of a pond "off-line" from active flowing streams reduces the impact to existing aquatic environment and does not necessarily inhibit fish migration.
- Diversion structures or "flow splitters" provide a technique for conveying both base flow and storm flow away from sensitive areas (see Figure 1).
- Pond grading techniques that provide storage volumes direct impacts away from sensitive areas.
- Pond grading techniques that give curvilinear geometry to the pond can increase flow lengths and decrease ineffective storage areas.
- Pond grading techniques that use shallow aquatic zones, peninsulas and/or islands, and low-lying areas for riparian vegetation provide varied water regimes.
- Incorporating vegetative practices into the design, such as shallow marsh emergent wetlands, submerged aquatic vegetation, and riparian fringe plantings, can create additional wildlife habitats.

Figure 2 depicts a wet pond concept for a warm water environment.

### *Cool Water Environments*

For cool water fisheries, where thermal impacts are a major consideration, a design must attempt to maximize pollutant removal efficiencies but also to reduce and/or offset thermal impacts.

The following are some of the techniques that incorporate these goals:

- The facility should avoid open bodies of water where solar radiation would heat up the water column. Examples in descending order of preference would be infiltration facilities, filtration facilities, dry extended detention ponds, and shallow stormwater wetland ponds (2).
- The location and orientation of the facility should account for the hours of potential solar radiation, such as a north/south dominant orientation.
- Shading of the pool area by maximizing tree canopy can minimize solar penetration.
- Incorporating underdrain and toe drain groundwater collection systems can provide an additional source of cool water release, where available, while implementing an earthen embankment safety consideration.
- Shading and covering a pond's outlet channel helps prevent thermal impacts associated with water running over heated rocks.
- Watershedwide landscaping, including shading of impervious asphalt surfaces, helps reduce thermal loading at the source.

Figure 3 depicts a dry pond concept for a cool water environment.

### *New Theorized Techniques*

New approaches may afford the opportunity to combine the pollutant removal efficiencies of wet ponds with temperature mitigation measures. Three approaches are to:

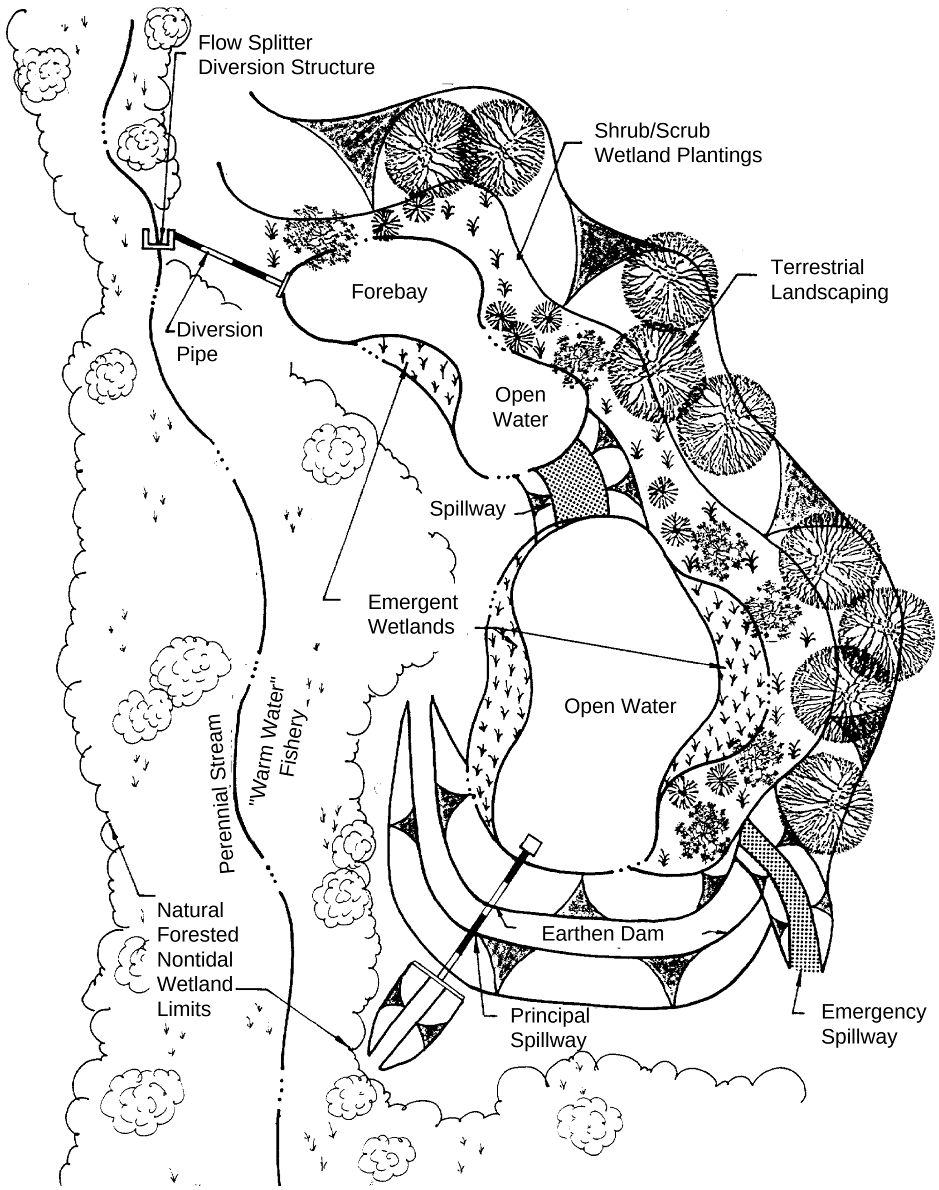


**Figure 2. Wet pond concept with diversion structure for warm water environment.**

- Incorporate "cooling tower" design practices into the outlet structure of the spillway system (Figure 4) (3).
- Investigate vegetative practices that cover the open water surface of ponds to minimize solar radiation of the water column (4).
- Incorporate a ground-water siphon system into the design of the release structures to siphon ground water as the low flow release (Figure 5) (5).

## Maintenance and Monitoring

An effective design cannot become a practical application without a good implementation program, an effective monitoring program, and a maintenance program that keeps a facility functioning at its best. Many of the techniques and considerations previously discussed are new and may not meet expectations. These techniques require short- and long-term monitoring to ensure that they are meeting the expectations of the designer and agency.

In addition, many of the more innovative design approaches require periodic maintenance. It is not practical to assume that these approaches will function without the necessary observations and periodic maintenance. Some of the approaches (e.g., flow splitters) require only periodic trash removal to keep them functioning as designed, while others (e.g., filters and infiltration basins) require a more intensive maintenance program.

## Conclusion

In sensitive areas, design approaches need to combine innovative alternatives, common sense, and compromise. Everyone agrees that our sensitive resources

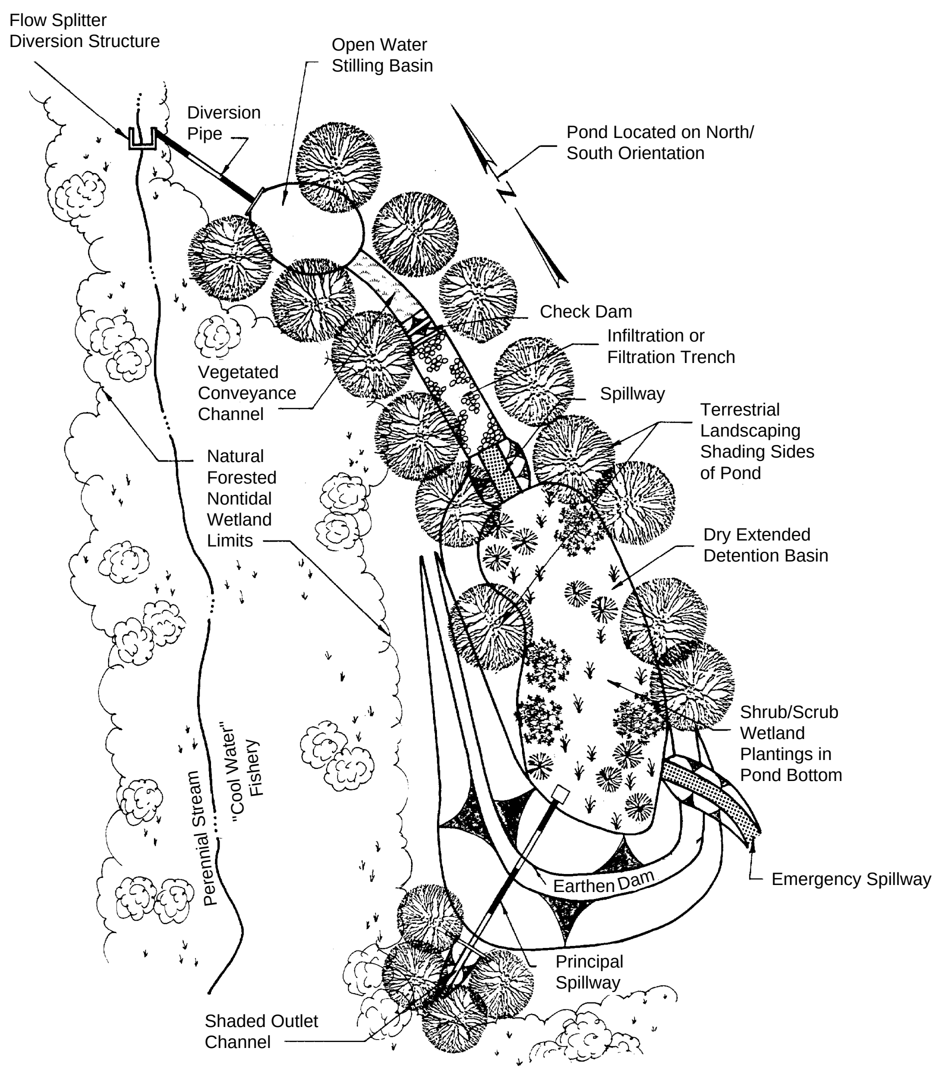


**Figure 3. Dry pond concept with diversion structure for cool water environment.**

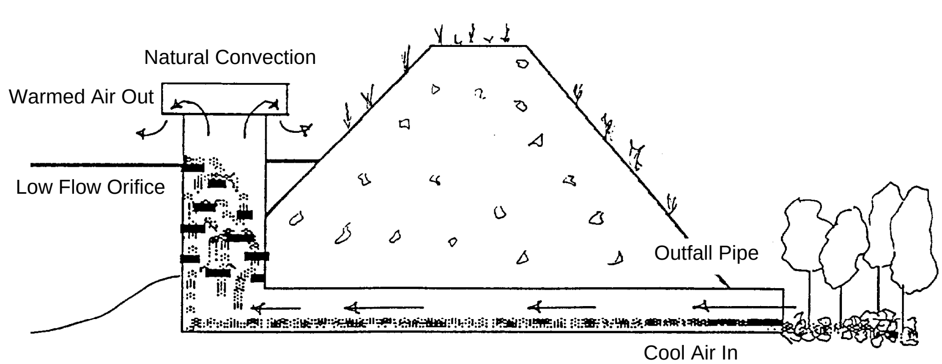


**Figure 4. Combination atmospheric and natural draft cooling tower to cool water discharged from a wet pond system (3).**

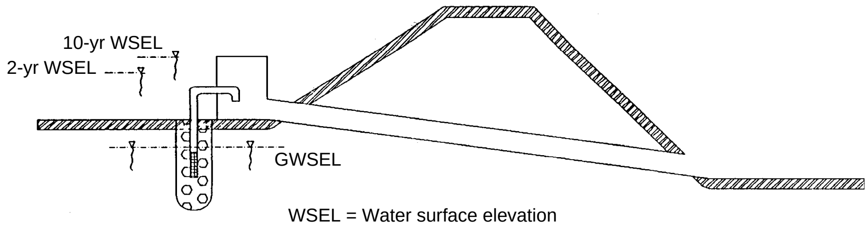


**Figure 5. Siphon thermal cooler concept for stormwater management ponds (5).**

need special protection and require the utmost care if a disturbance occurs. There is not agreement, however, on the best approaches and on what resources are the most important. Therefore, it is vital to document the existing conditions carefully, prepare flexible concepts and designs, and be prepared to revise plans and design approaches as new information and monitoring results emerge. Practical aspects of stormwater pond design will not remain static but will continue to change as new technologies and techniques advance and older considerations become obsolete.

## Acknowledgments

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# *Infiltration Practices: The Good, the Bad, and the Ugly*

**Eric H. Livingston**
**Florida Department of Environmental Regulation,**
**Tallahassee, Florida**

## Abstract

Of all the best management practices (BMPs) in the stormwater treatment tool box, infiltration practices are the most effective in removing stormwater pollutants and, equally important, in reducing both stormwater volume and peak discharge rate. This paper explains the concept of on-line and off-line systems, and discusses factors that influence their treatment effectiveness. Design guidelines for infiltration systems, including the importance of the BMP treatment train approach, will be reviewed, focusing on soil types, water table elevation, geology, vegetation, and determination of infiltration rates. Construction considerations will be reviewed. Because of their likelihood for clogging, the importance of regular inspection and maintenance programs is stressed.

Infiltration practices that the paper covers include roadside swales, retention basins, landscape retention, exfiltration systems, infiltration trenches, and porous pavement. For each type of system, information on treatment effectiveness, design criteria, advantages, and disadvantages is presented, along with discussion of the good, the bad, and the ugly. The paper reviews the effect of infiltration practices on ground-water quality and presents recommendations to limit adverse impacts. Special design guidelines for infiltration practices in areas with karst geology, which is characterized by sinkholes, will also be reviewed.

## Introduction

To achieve the desired objectives of flood and water quality protection, erosion control, improved aesthetics, and recreation, a stormwater management system must be an integral part of the site planning for every site. Although the basic principles of stormwater management remain the same, each individual site and each specific project presents unique challenges, obstacles, and opportunities. The many variations in climate, soils, geology, ground water, topography, vegetation, and planned land use require site-specific design. Each site contains natural attributes that will influence the type and configuration of the stormwater system.

The variety of features contained on a site suggest which particular combination of best management practices (BMPs) can be successfully integrated into an effective system. Whenever site conditions allow, the stormwater management system should be designed to achieve maximum onsite storage (and even reuse) of stormwater by incorporating infiltration practices throughout the remaining natural and landscaped areas of a site. A stormwater management system should be viewed as a "treatment train" in which the BMPs are the individual cars. Generally, the more BMPs that are incorporated into the system, the better the performance of the treatment train. Inclusion of infiltrative practices as one of the cars should be a primary goal of stormwater system designers.

Infiltration practices are one of the few BMPs that can help to ensure that all four stormwater characteristics (the volume, rate, timing, and pollutant load) after development closely approximate the conditions that occurred before development. This is because infiltration practices help to maintain predevelopment site perviousness and vegetative cover, thereby reducing stormwater volume and discharge rate, which further promotes infiltration and filtering of the runoff.

The benefits of infiltration include:

- Reducing stormwater volume and peak runoff rate.
- Recharging ground water, which helps to replenish wetlands, creeks, rivers, lakes, and estuaries.
- Augmenting base flow in streams, especially during low flow times.
- Aiding in the settling of pollutants.
- Lowering the probability of downstream flooding, stream erosion, and sedimentation.
- Providing water for other beneficial uses.

Another benefit of infiltration practices is their ability to serve multiple uses because they are temporary storage basins. Recreational areas (e.g., ballfields, tennis courts, volleyball courts), greenbelt areas, neighborhood parks, and even parking facilities provide excellent settings for the temporary storage of stormwater. Such areas are not usually in use during periods of precipitation, and the ponding of stormwater for short durations does not seriously impede their primary functions.

## Determining Treatment Effectiveness

To design a BMP for water quality enhancement, a pollutant reduction goal must first be established. Stormwater treatment regulatory programs in Florida and Delaware are based on a performance standard of reducing the annual average total suspended solids (pollutant) load by 80 percent for stormwater systems discharging to waters classified as fishable and swimmable. In Florida, stormwater systems discharging to potable supply waters, pristine waters, or highly polluted waters may be required to remove up to 95 percent of the average annual pollutant load. Technology-based performance standards such as these provide water quality goals for nonpoint sources that create equity with the minimum treatment requirements for domestic wastewater point sources (1). Design criteria for various types of stormwater management systems that achieve the desired performance standard (treatment efficiency) are then adopted, thereby providing guidance to the design community and making it relatively easy to obtain a stormwater permit.

The average annual pollutant removal efficiency is calculated by considering the annual mass of pollutants available for discharge and the annual mass removed. The primary removal mechanism for infiltration practices is the volume of stormwater that is infiltrated, because this eliminates the discharge of stormwater and its associated pollutants. As with any type of stormwater management practice, its actual field efficiency depends on many factors. For infiltration practices, these factors include:

- Long-term precipitation characteristics such as mean number of storms per year along with their intensity and volume; average interevent time.
- The occurrence of first flush, which is related to the amount of directly connected impervious area, type of stormwater conveyance system, and the pollutant of interest.
- “On-line” or “off-line” design.

Cumulatively, the above three factors determine the minimum treatment volume and maximum storage recovery time.

The National Weather Service (within the National Oceanic and Atmospheric Administration) has measured weather statistics at many locations around the country. Long-term precipitation records, including information such as day and duration of event, intensity, and volume, are available from either the federal government or private vendors. Statistical analysis of these records can develop probability frequencies for storm characteristics such as the mean storm volume and the mean interevent period between storms.

“First flush” describes the washing action that stormwater has on accumulated pollutants in the watershed. In the early stages of runoff, the land surfaces, especially impervious ones such as streets and parking areas, are flushed clean by the stormwater. This flushing creates a shock loading of pollutants. The occurrence and prevalence of first flush, however, depends largely on precipitation patterns. Studies in Florida have determined that for urban land uses there is a first flush for many pollutants, especially particulates (2, 3). In areas such as Oregon and Washington, however, where rainfall consists of low intensity, long-duration “events,” the first flush is not very prevalent. Where it exists, the first-flush effect generally diminishes as the size of the drainage basin increases and the amount of impervious area decreases.

On-line stormwater practices store runoff temporarily before most of the volume is discharged to surface waters. These systems capture all of the runoff from a design storm. This mixes all stormwater within the system, thereby masking first flush and reducing pollutant removal. They primarily provide flood control benefits, with water quality benefits usually secondary, although on-line wet detention systems do provide both benefits.

Off-line practices are designed to divert the more polluted stormwater first flush for water quality treatment, isolating it from the remaining stormwater that is managed for flood control. The diverted first flush is not discharged to surface waters but is stored until it is gradually removed by infiltration, evaporation, and evapotranspiration. Vegetation, such as grass in the bottom and sides of infiltration areas, helps to trap stormwater pollutants and reduce the potential for transfer of these pollutants to ground waters. Off-line retention practices are the most effective for water quality enhancement of stormwater.

Because an off-line retention area primarily provides for stormwater treatment, it must be combined with other BMPs for flood protection to form a comprehensive stormwater management system. Figure 1 is a schematic of an off-line system, commonly referred to as a “dual pond system,” in which a smart weir directs the first flush stormwater into the infiltration area until it is filled, with the remaining runoff routed to the detention facility for flood control.

Using the three factors above, design criteria have been developed and implemented in Florida to achieve the

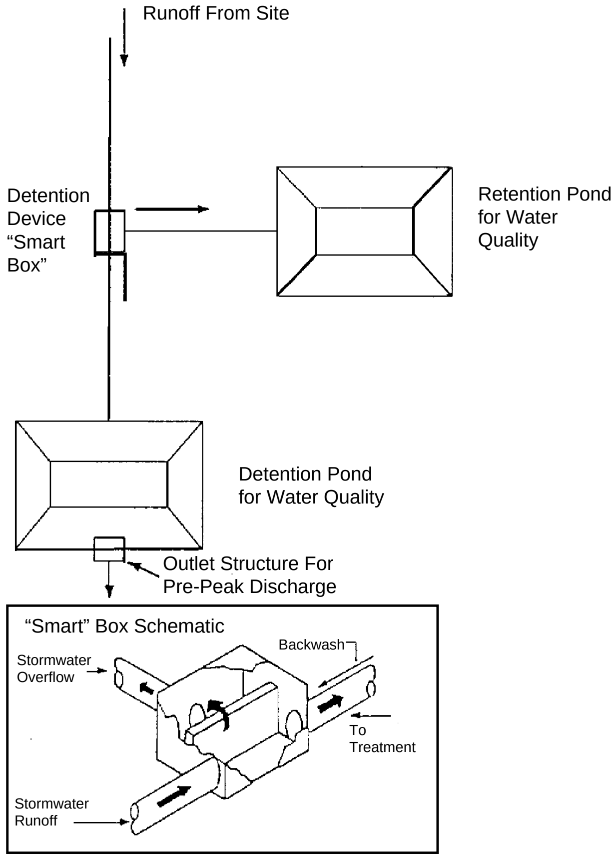


**Figure 1. Schematic of an off-line system (4).**

desired 80 or 95 percent treatment performance standard (5). The pollutant removal efficiency of an off-line system depends on the annual volume of stormwater that is diverted and infiltrated. For each storm, pollutant removal efficiencies will vary from 100 percent for storms producing less runoff than the diversion design volume to lower efficiencies for much larger storms. If the time between storms is less than the design interevent period, then the design treatment volume will not be available, and more runoff will not be captured and treated. Wanielista (6) developed cumulative frequency distributions for storm-related efficiencies using a simulation model dependent on 20 years of rainfall data and 16 measured storm event runoff quantities and qualities. The results shown in Table 1 are based on Florida rainfall characteristics (90 percent of all annual rainfall events are less than 2.54 cm) and a distinct first flush (up to 90 percent of the pollution load carried in the first 2.54 cm of runoff). An off-line retention system designed to accept at least the first 1.25 cm of runoff (or the volume calculated by 1.25 times the percent imperviousness of the site) will remove more than 80 percent of the average annual pollutant load.

A more recent investigation of the influence of long-term rainfall characteristics on the efficiency of retention practices led to the development of diversion volume curves for interevent dry periods of varying length (7). Figure 2 shows an example diversion volume curve for the Orlando area. It is important to note that first flush is not considered in these curves. If a first-flush effect does exist, the design curves would be conservative in that the percent treatment efficiency of the infiltration system would increase. Furthermore, these curves are based on precipitation interevent frequency (PIF) curves, which also include consideration of the probability that a storm greater than the design storm will occur. The PIF analysis looked at exceedance probabilities for storms with a return period of 2, 3, 4, or 6 months, representing a chance that the storm will exceed the design volume six, four, three, or two times a year.

**Table 1. Cumulative Frequency Distributions on Efficiencies per Storm Event as a Function of Storage Volume (Area = 4.6 Ac, 85 percent Impervious, Tc = 20 min)**

| | Volume of Storage, centimeters (inches) | | | |
|---|---|---|---|---|
| **Average[a] Efficiency** | **0.25 (0.1)** | **0.64 (0.25)** | **1.27 (0.50)** | **2.54 (1.0)** |
| 100 | 35.4 | 66.4 | 92.9 | 99.0 |
| >96 | 42.5 | 74.3 | 97.3 | 100.0 |
| >92 | 46.0 | 77.9 | 97.4 | |
| >88 | 47.8 | 81.4 | 98.2 | |
| >84 | 50.4 | 90.3 | 100.0 | |
| >80 | 65.6 | 92.9 | | |
| >76 | 61.1 | 96.3 | | |
| >72 | 66.4 | 97.3 | | |
| >68 | 72.6 | 98.2 | | |
| >64 | 82.3 | 100.0 | | |

[a] Average efficiency is the average removal of $BOD_5$, suspended solids, nitrogen, and phosphorus over a 20-year period. Average number of rainfall events producing runoff per year is 116.

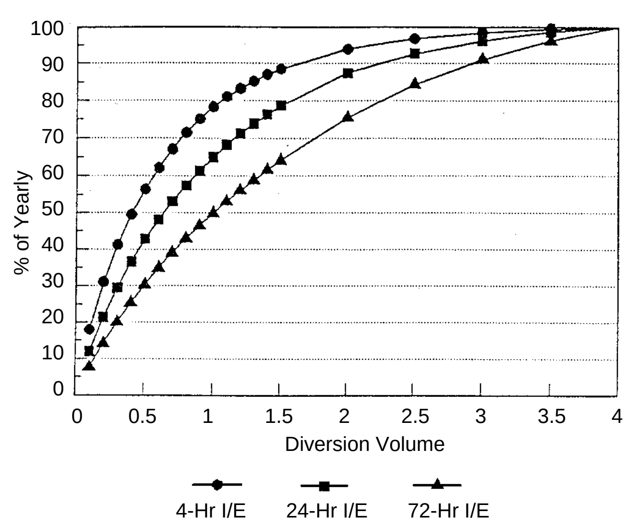


**Figure 2. Diversion volume curve for Orlando, Florida.**

## Design of Infiltration (Retention) Practices

Infiltration practices also are commonly called retention practices because they retain the runoff on site. They are designed to infiltrate a design volume (treatment volume) of stormwater, and the tool box includes on-line and off-line percolation ponds and trenches, infiltration areas, exfiltration systems, and vegetated swales. Design factors that influence the treatment effectiveness and feasibility of infiltration practices include choice of on-line or off-line system, use of the BMP treatment train concept, and soil type, geology, water table elevation, topography, and vegetation.

Infiltration areas, especially off-line ones, can be incorporated easily into landscaping or open space areas of a site. These can include natural or excavated grassed depressions, recreational areas, and even parking lot landscape islands. If site conditions prevent the exclusive use of infiltration, then off-line retention areas should be used as pretreatment practices in a stormwater treatment train. This is especially true if detention lakes are the primary component of the stormwater system and the lakes are intended to serve as a focal point of the development. Parking lots with their landscape islands offer an excellent opportunity for the use of this concept because even the infiltration of a quarter inch of runoff will greatly reduce sediments, metals, and oils and greases. Placing storm sewer inlets within recessed parking lot landscape areas, raising the inlet a few inches above the bottom, and using curb cuts to allow runoff to enter this area represent a highly effective treatment train.

## Siting, Design, and Planning Considerations for Infiltration Practices

The suitability of a site for certain infiltration practices depends on a careful evaluation of the site's natural attributes. Proposed infiltration areas should be evaluated for feasibility on any particular site or project by examining the following.

### *Soils*

Soils must have permeability rates that allow the diverted volume to infiltrate within 72 hours, or within 24 to 36 hours for infiltration areas that are planted with grasses. Soil textures with minimum infiltration rates of 0.43 cm/hr or less are not suitable for infiltration practices (8). These unsuitable soils include soil textures that have at least 30 percent clay content.

### *Infiltration Rates*

One of the most difficult aspects of designing infiltration practices is obtaining reliable information about the actual infiltration rate of the soil where the practice will be constructed. Unfortunately, such information is not easily obtainable. Avellaneda (9) conducted 20 hydrologic studies of vegetated swales constructed on sandy soils with a water table at least 1 ft below the bottom during dry conditions. Infiltration rates were measured using laboratory permeability tests, double-ring infiltrometers, and field mass balance experiments. The field mass balance method measured a minimum infiltration rate of 5 to 7.5 cm/hr. This measured rate was much less than lab permeabilities, rates measured by double-ring infiltrometer tests (12.5 to 51 cm/hr), or rates published in the detailed soil survey. Recommendations for determining the infiltration rate for retention practices include the following:

- Because the infiltration rate is the key to designing any retention practices, conservative estimates should be used and safety factors incorporated into the design to ensure that the design volume will actually be percolated into the soil and not discharged downstream.
- Onsite infiltration measurements must be taken at the locations where retention practices will be located. More importantly, because soil characteristics and infiltration rate change with depth, it is crucial that the measurements be made at the depth of the design elevation of the bottom of the retention practice.
- Infiltration rates should be determined by mass balance field tests if possible. These provide the most realistic estimate of the percolation rate. If field tests are not possible, then infiltrometer tests should be used, with lab permeability tests a third option. In either of these two tests, the design infiltration rate should be half of the lowest measured rate. As a last resort, information from detailed soil surveys can be used to estimated the infiltration rate. The lowest rate should be used, however, as should a safety factor of two.

### *Water Table*

The seasonal high water table should be at least 1 m beneath the bottom of the infiltration area to ensure that stormwater pollutants are removed by the vegetation, soil, and microbes before contacting the ground water. When considering the ground-water elevation, it is important to remember that the retention area can cause a mounding effect on the water table, thereby raising it above the predevelopment level.

### *Geology*

Bedrock should be at least 1 m beneath the bottom of the infiltration area. In those parts of the country where limestone is at or near the land surface, special precautions must be taken when using infiltration practices. The potential for ground-water contamination in such areas is quite high, especially in "karst sensitive areas" (KSAs), where sinkhole formation is common. In KSAs, solution pipe sinkholes may form in the bottom of infiltration areas, creating a direct conduit for stormwater pollutants to enter the ground water. Solution pipes often open in the bottom of retention areas because the natural soil plug capping the solution pipe is thinned by partial excavation to create the retention area and because the stormwater creates hydraulic pressure that can wash out the plug.

In KSAs, a site-specific hydrogeologic investigation should be undertaken that includes geologic borings wherever infiltration areas are proposed and mapping limerock outcroppings and sinkholes on site. Infiltration systems in KSAs should:

- Include several small offsite areas.
- Use swale conveyances for pretreatment.
- Be as shallow as possible.
- Be vegetated with a permanent cover such as sodded grasses.
- Have flat bottoms to keep the stormwater spread out across the entire area.

### *Topography*

Infiltration practices should not be located on areas with slopes over 20 percent to minimize the chance of downstream water seepage from the subgrade. Sloping sites often require extensive cut and fill operations. Infiltration practices should not be sited on fill material because fill areas are very susceptible to slope failure, especially when the interface of the fill/natural soil becomes saturated.

### *Vegetation*

To reduce the potential for stormwater pollutants to enter ground waters and to help maintain the soil's capacity to absorb water, infiltration practices should be vegetated with appropriate native vegetation, especially grasses. This type of vegetation cannot tolerate long-term inundation, however, so the retention area must be capable of infiltrating all of its runoff within a relatively short period (i.e., 24 to 36 hours).

### *Set Backs*

Infiltration areas should be located at least 33 m from any water supply well and at least 3.5 m downgradient from any building foundations. Additionally, they should be set back at least 15 m from onsite wastewater systems, especially drain fields.

### *Land-Use Restrictions*

Certain infiltration practices can only be applied to particular land uses. Some sites are so small or intensively developed that space is insufficient for practices that require a large area (e.g., retention basin). Other practices (e.g., porous pavement) can only be used on sites with parking lots and limited truck traffic.

### *Sediment Input*

Infiltration practices must be protected from large loads of sediment to prevent clogging and subsequent failure. Although sediment loads drop sharply after construction is complete, gradual clogging of infiltration practices can still occur. Pretreatment practices such as swale conveyances or vegetated buffer strips can help to filter out sediments and extend the life of retention practices.

### *Construction Considerations*

To prevent clogging of infiltration areas, special precautions must be taken during the entire construction phase of a project. These are needed to prevent sedimentation during construction, compaction of the soil, and subsequent reduction in its infiltration capacity. Areas with suitable characteristics that are selected for infiltration use should be well marked during site surveying and protected during construction. Heavy equipment, vehicles, and sediment laden runoff should be kept out of infiltration areas to prevent compaction and loss of infiltration capacity.

- Before the development site is graded, the area planned for use as infiltration areas should be well marked during site surveying. Then, the area should be roped off to prevent heavy equipment from compacting the underlying soils.
- Diversion berms should be placed around the perimeter of the infiltration area during all phases of construction. Sediment and erosion control plans for the site should be oriented to keep sediment and runoff completely away from the area. Actual construction of the infiltration practice should not begin until after the site has been stabilized completely.
- Infiltration areas should never be used as a temporary sediment basin during the construction phase. It is somewhat common for infiltration areas, especially basins, to be used as a sediment trap, with initial excavation to within 2 ft of the final design elevation of the basin floor. Sediment that accumulates during the construction phase can then be removed when the basin undergoes final excavation after the development has been completed. Recent experience, however, indicates that even with this type of construction practice infiltration areas used as sediment traps tend to fail.
- Infiltration areas/basins should be excavated using light earth-moving equipment with tracks or oversized tires. Normal rubber tires should be avoided because they compact the subsoil and reduce its infiltration capabilities. For the same reason, the use of bulldozers or front-end loaders should be avoided. Because some

compaction of the underlying soils is still likely to occur during excavation, the floor of the basin should be deeply tilled with a rotary tiller or disc harrow.

- The basin should be stabilized with vegetation within a week after construction. Use of low maintenance, rapid-germinating grasses such as fescues are recommended. The condition of the newly established vegetation should be checked several times over the first 2 months and any necessary remedial actions taken (e.g., reseeding, fertilization, and irrigation).

### *Maintenance*

All infiltration practices require regular and nonroutine maintenance to maintain their ability to infiltrate stormwater. The frequency and need for maintenance depends primarily on the loading of particulates and the use of pretreatment practices. Inspections should be conducted on a regular basis after storm events, and maintenance activities should be conducted whenever stormwater remains in the practice beyond the designed time. Specific maintenance needs are discussed for each of the different types of infiltration practices in the next section.

## Discussion of Various Infiltration Practices

### *Infiltration Basins*

An infiltration basin is made by constructing an embankment or by excavating in or down to relatively permeable soils. The basin temporarily stores stormwater until it infiltrates through the bottom and sides of the system. The infiltration “basin” can actually be a landscape depression within open spaces, even parking lot islands or a recreational area such as a soccer field. Infiltration areas generally serve drainage areas ranging from 2 to 20 hectares. Infiltration basins should be designed as off-line systems but they can be on-line, especially if predevelopment stormwater volume is being maintained.

Advantages of infiltration basins are that they preserve the natural water balance of a site, can serve larger developments, and can be integrated into a site’s landscaping and open spaces. Disadvantages of infiltration basins can include their land area; fairly high rate of failure due to unsuitable soils, poor construction, or lack of maintenance; the need for frequent maintenance; and possible nuisances such as odors, mosquitos, or soggy ground (all signs of a failing system).

The function of infiltration basins can be improved if the following design tips are followed:

- *Basin floor and sides:* The rate and quantity of infiltration are enhanced by increasing the surface area of the bottom. Large, relatively shallow areas are preferable, especially in KSAs, so that the stormwater spreads evenly over the entire surface area. Therefore, it is very important that the bottom be evenly graded with a zero slope. If the bottom is uneven, these low spots will remain underwater for a longer time and may become chronically wet as the floor clogs and infiltration is reduced. Side slopes should be no steeper than 3:1 to allow for vegetative stabilization, easier mowing and access, and better public safety.

- *Vegetation:* The side slopes and bottoms of infiltration areas should be vegetated with a dense turf of water-tolerant grass immediately after construction. Not only does the vegetation stabilize these areas, but it also helps to filter stormwater pollutants, remove dissolved nutrients and metals, enhance aesthetic qualities, reduce maintenance needs, and even maintain or improve infiltration rates.

- *Reducing incoming water velocities:* Inlets to an infiltration area should be stabilized to prevent inflowing runoff velocities from reaching erosive levels and scouring the bottom. Riprapping inlet channels or pipe outfalls and using bubble-up inflow devices or perimeter swale and berms can address this problem. Because the stormwater should spread evenly over the entire infiltration area, riprap inlets should terminate in a broad apron that serves as a crude level spreader.

- *Construction requirements:* Proper construction and routine maintenance as discussed above are essential for successful infiltration basin implementation. In a recent survey, approximately 40 percent of the infiltration basins had partially or totally clogged within their first few years of operation (10). Many of the systems failed almost immediately after construction or never worked properly from the beginning.

- *Routine maintenance requirements:* Infiltration areas should be inspected following major storms, especially in the first few months after construction. If stormwater remains in the system beyond the design drawdown time (typically 24 to 36 hours if grassed, 48 to 72 hours if not grassed), either the infiltration capacity was overestimated or maintenance is needed. Factors responsible for clogging may include upland erosion and sedimentation, low spots, excessive compaction, or poor soils. Cleaning frequently depends on whether the basin is vegetated or nonvegetated and is a function of storage capacity, sediment and debris load, and land use. Litter, leaves, brush, and other debris should be removed regularly, perhaps during the mowing of vegetation. The buffer, side slopes and bottom of the retention area should be mowed as needed, with the grass clippings removed. Eroded or barren areas should be immediately revegetated. Nonvegetated basins can be tilled annually after accumulated sediments are removed. Sediments should be removed only after the basin is thoroughly dry, preferably to the point where the top layer begins to crack. To reduce soil compaction, only light equipment should be used.

- *Nonroutine maintenance requirements:* Over time, the original infiltration capacity of the bottom will gradually decline. Deep tilling every 5 to 10 years can be used to break up clogged surface layers, followed by regrading, leveling, and revegetation. If the original infiltration rate was overestimated, underdrains may be installed beneath the bottom, or perhaps the system should be converted to a shallow marsh or wet detention system.

### *Infiltration Trenches*

An infiltration trench generally consists of a long, narrow excavation, ranging from 1 to 3 m in depth, that is backfilled with stone aggregate, allowing for the temporary storage of the first-flush stormwater in the voids between the aggregate material. Stored runoff then infiltrates into the surrounding soil. To minimize clogging potential and maximize treatment effectiveness, infiltration trenches should always be designed as off-line systems. Infiltration trenches usually are designed to serve drainage areas of 2 to 4 hectares and are especially appropriate in urban areas where land costs are prohibitive. As with any infiltration practice, the treatment train concept must be employed to capture sediment before it enters the trench to minimize and reduce clogging.

Advantages of infiltration trenches include ground-water recharge, reduced stormwater volume, and the ability to fit into perimeters or other underused areas of a development, even beneath parking areas. Disadvantages include potential clogging, especially if sediment is not kept out during construction, the need for careful design and construction, and maintenance.

Infiltration trenches can be located on the surface or below the ground. Surface trenches receive sheet flow runoff directly from adjacent areas after it has been filtered by a grass buffer. Underground trenches can accept runoff from storm sewers but require use of special pretreatment inlets to prevent coarse sediment, soils, leaves, and greases from clogging the stone reservoir.

Surface trenches typically are used in residential areas where smaller loads of sediment and oil can be trapped by grass filter strips that are at least 6 m wide. While surface trenches may be more susceptible to sediment accumulations, their accessibility makes them easier to maintain. Surface trenches can be used in highway medians, parking lots, and narrow landscape areas.

Underground trenches can be applied in many development situations and are particularly suited to accept concentrated runoff; however, pretreatment is essential. Inlets to underground trenches should include trash racks, catch basins, and baffles to reduce sediment, leaves, debris, and oil and grease. Maintenance of underground trenches can be very difficult and expensive, especially if placed beneath parking areas or pavement.

The most commonly used underground trench is an exfiltration system, in which the stormwater treatment volume is diverted into an oversized perforated pipe placed within an aggregate envelope. The first-flush stormwater is stored in the pipe and exfiltrates out of the holes, through the gravel and filter fabric, and into the surrounding soil. The city of Orlando, Florida, has installed exfiltration systems using perforated corrugated metal pipe and slotted concrete pipe throughout the downtown area to reduce stormwater pollution of its lakes.

Dry wells are used extensively in Maryland to store and infiltrate runoff from rooftops. The downspout from the roof gutter is extended into an underground trench, which is constructed at least 3 m away from the building foundation. Rooftop gutter screens are used to trap particles, leaves, and other debris. Additional design information on dry wells is available from the Maryland Department of the Environment (11).

The following design and construction guidelines are provided for infiltration trenches.

#### Infiltration Rates

The actual rate at which water leaves the infiltration trench is determined by several factors. Whether infiltration primarily occurs through the trench bottom or sides depends on the elevation of the water table and soil properties. To prevent ground-water contamination, trench bottoms should be at least 4 ft above the seasonal high water table (remember to consider ground-water mounding). This will also ensure infiltration through the bottom. In addition to the infiltration rate of the parent soil, the permeability of the surrounding filter fabric (if used) is crucial and can become a limiting factor. A recent investigation of exfiltration systems (12) provides the following:

- Permeability of the parent soil is not the limiting exfiltration rate.
- The limiting exfiltration rate is set by the geotextile filter fabric, not the soil.
- A maximum rate of 1.27 cm/hr should be used, assuming infiltration through the sides and bottom.
- A maximum rate of 2.54 cm/hr should be used if the geotextile filter fabric is matched correctly to the soil type and only the trench side areas are assumed to exfiltrate.

#### Construction of Infiltration Trenches

Successful use of infiltration trenches requires thorough site planning and evaluation and proper construction. In addition to the construction recommendations for all infiltration practices discussed above, the construction of infiltration trenches should also include the following:

- Excellent erosion and sediment control should be maintained during construction to keep sediments away from the trench. Allowing even an inch or two of soil to get into the trench between the aggregate and the fabric will almost ensure clogging. If constructed before the drainage area is entirely stabilized, then the trench should be covered with heavy plastic to prevent any inflow until stabilization is completed.

- The trench should be excavated using a backhoe or trencher equipped with tracks or oversized tires. Normal rubber tires should be avoided because they compact the subsoil and may reduce infiltration capability. For the same reason, the use of bulldozers or front-end loaders should be avoided. Excavated material should be stored at least 3 m from the trench to avoid backsliding and cave-ins.

- Once the trench is excavated, the bottom and sides should be lined with a geotextile filter fabric to prevent upward piping of underlying soils. The fabric should be placed flush with the sides and bottom, with a generous overlap at the seams. Care should be taken in selecting the proper kind of filter fabric, as available brands differ significantly in their permeability and strength. The geotextile fabric must be handled carefully to prevent holes and tears that allow soil to get into the trench. As an alternative, a 15-cm deep filter of clean, washed sand may be substituted for filter fabric on the bottom of the trench.

- Clean, washed 2.5- to 7.5-cm stone aggregate should be placed in the excavated reservoir in lifts and lightly compacted with plate compactors to form the coarse base. Unwashed stone has enough associated sediment to pose a risk of clogging at the soil/filter cloth interface. Where possible, the use of limestone or bluestone aggregate should be avoided.

- A simple observation well should be installed in every trench. Wells can be made of secure foot plate, perforated polyvinyl chloride pipe, and locking cover. The observation well is needed to monitor the performance of the trench and is also useful in marking its location. The drain time for a trench can be measured by placing a graduated dipstick down the well immediately after a storm and again 24, 48, and 72 hours later.

- Postconstruction sediment control is critical. It is therefore important that 1) sediment and erosion controls be inspected to make sure they still work, 2) vegetated buffer strips are established immediately, preferably by sodding, and 3) if hydroseeding is used, reinforced silt fences are placed between the buffer and trench to prevent sediment entry before the buffer becomes fully established.

**Maintenance of Infiltration Trenches**

If properly constructed with pretreatment practices to prevent heavy sediment loading, infiltration trenches can provide stormwater benefits without tremendous maintenance needs. Because trenches are "out of sight, out of mind," getting property owners to maintain them can be difficult. Accordingly, a public commitment for regular inspection of privately owned trenches is essential, as is a legally binding maintenance agreement and education of owners about the function and maintenance needs of trenches.

Trenches should be inspected frequently within the first few months of operation and regularly thereafter. Inspections should be done after large storms to check for water ponding, with water levels in the observation well recorded over several days to check drawdown. Grass buffer strips should maintain a dense, vigorous growth of grass and receive regular mowing (with bagging of grass clippings) as needed. Pretreatment devices should be checked periodically and sediment removed when the sediment reduces available capacity by more than 10 percent.

### *Swales*

Swales, or grassed waterways, are one of the oldest stormwater BMPs, having been used along streets and highways and by the farmer for many years. By definition, a swale is a shallow trench that:

- Has side slopes flatter than 3 ft horizontal to 1 ft vertical.
- Contains contiguous areas of standing or flowing water only following a rainfall.
- Is planted with or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.
- Is designed to take into account the soil erodability, soil percolation, slope, slope length, and drainage areas so as to prevent erosion and reduce stormwater pollutants.

Traditionally, swales have been and are used primarily for stormwater conveyance; as such, they are considered an on-line practice. The removal of stormwater pollutants by swales can occur by either infiltration or vegetative filtration and uptake. Investigations in Florida (13, 14) have concluded that swale treatment efficiency largely depends on the volume of stormwater that can be infiltrated through the filtering vegetation and into the soil. To achieve Florida's performance standards, swales must be designed to infiltrate the runoff from a 3-yr/1-hr storm (about 7.5 cm) within 72 hours. Investigations in Washington state (15, 16), however, indicate that swales can also act as a biofilter, with removal of particulate pollutants without infiltration of stormwater.

Avellaneda (9) developed the following equation for a triangular shaped swale to estimate the length of swale necessary to infiltrate the design runoff volume:

$$L = \frac{KQ^{5/8} S^{3/16}}{n^{3/8} i} \qquad (1\text{–}1)$$

where:

L = swale length (m)
n = Mannings roughness coefficient
Q = average runoff flow rate ($m^3$/sec)
i = infiltration rate (cm/hr)
S = longitudinal slope (m/m)
K = constant that is a function of side slope (see Table 2)

For most residential, commercial, and highway projects, the length of swales necessary to percolate the stormwater needed to achieve the 80 percent performance standard was found to be excessive or at least twice the distance available. Thus, some type of swale block (berm) or on-line detention/retention may be more helpful. Swales make excellent pretreatment practices by providing for the infiltration of some stormwater and for some vegetative filtration. By using a raised stormsewer inlet, swales can provide water quality enhancement via retention and still serve as effective conveyances for flood protection. Swales can incorporate retention by using swale blocks, small check dams, or elevated driveway culverts to create storage, thereby reducing runoff velocity, reducing erosion, and promoting infiltration.

Using the runoff from 7.5 cm of rainfall as a design treatment volume, equations have been developed for swale block designs to store and infiltrate the runoff (17).

**Table 2. Constant (K) for Design Equation for Triangular Shape**

| **Z (Side Slope)** ($\frac{\text{1 Vertical}}{\text{Z Horizontal}}$) | **K (U.S. Units)** | **K (SI Units)** |
|---|---|---|
| 1 | 10,516 | 75,552 |
| 2 | 9,600 | 68,971 |
| 3 | 8,446 | 60,680 |
| 4 | 7,514 | 53,984 |
| 5 | 6,784 | 48,740 |
| 6 | 6,203 | 44,565 |
| 7 | 5,730 | 41,167 |
| 8 | 5,337 | 38,344 |
| 9 | 5,006 | 35,966 |
| 10 | 4,722 | 33,925 |

The swale block volume can be calculated for a fixed length of swale using:

Volume of runoff – volume infiltrated = swale block volume

$$Q\,(\Delta t) - Q_i\,(\Delta t) = \text{swale block volume}$$

$$Q\,(\Delta t) - \left[\frac{L\, n^{3/8}\, i}{K\, S^{3/16}}\right]^{8/5} (\Delta t) = \text{swale block volume} \qquad (1\text{–}2)$$

where

$Q_i$ = average infiltration rate ($m^3$/sec)
$\Delta t$ = runoff hydrograph time (sec)

Wanielista and Yousef (18) present the following example problem using Equations 1 and 2 for designing a swale with cross blocks to satisfy a specific water quality goal:

Given

n = 0.05
i = 7.5 cm/hr
S = 0.0279
z = 7
$Q_i$ = 0.0023$m^3$/sec for $\Delta t$ = 100 min

what swale length would be necessary to percolate all the runoff?

Using Equation 1,

$$L = \frac{41{,}167\,(0.0023)^{5/8}\,(0.0279)^{3/16}}{(0.05)^{3/8}\;7.5} = 193 \text{ meters.}$$

If only 76 m is available, how much storage volume is necessary?

Using Equation 2,

$$(0.0023)(60)(100) - \left[\frac{(76)(0.05)^{3/8}\,(7.5)}{41{,}167\,(0.0279)^{3/16}}\right]^{8/5} 60(100) = \text{volume,}$$

and the volume of storage is equal to 10.7 $m^3$.

In highway designs for high-speed situations, safety must be considered; thus, a maximum depth of water equal to 0.5 m (about 1.5 ft) and flow line slopes on the berms of 1 vertical/20 horizontal are recommended. Along lower speed highways or in some residential/commercial urban settings, steeper flow line berm slopes (1/6) are acceptable.

The studies of swales in Washington state resulted in the following recommendations to improve water quality benefits (15):

- Maximum design velocity should not exceed 27 cm/sec.
- A hydraulic residence time of at least 9 min is recommended for removal of about 80 percent of the total suspended solids. Longer residence times will provide higher removal effectiveness.
- Swale width should be limited to 2 to 2.5 m unless special measures are provided to ensure a level swale bottom, uniform flow spreading, and management of flows to prevent formation of low-flow channels.
- Swale slopes should be between 2 and 4 percent.
- Water depth should be limited to no greater than one half the height of the grass, up to a maximum of 7.5 cm.
- Swale length will be a function of the hydraulic residence time, swale width, and stormwater volume and velocity.

### *Porous Pavement*

Local land development codes typically specify the type of material for a parking lot (i.e., paved, grass, gravel) and determine the number and size of parking spaces within a parking lot. These requirements should be reviewed carefully to ensure that they are necessary (Is paving really required in every case?) and that the number of spaces is related to actual traffic demands. After these requirements have been reviewed and verified, the use of porous pavement within a parking lot should be examined. Porous pavement materials include porous asphalt, porous concrete, turf blocks, and even Geoweb covered with sod.

Overall, experiences with porous pavements have not been very good. Porous pavements have been prone to clogging. Causes include poor erosion and sediment control during construction, unstabilized drainage areas after construction, improper mixing and finishing of the pavement, and poor maintenance. Field investigations of porous concrete that has been in use for up to 15 years in Florida, however, indicate that these parking lots can continue to infiltrate rainfall and runoff if they were installed and maintained properly (19). Recommendations to improve the utility of porous pavements include the following:

- Be sure that the installer is properly trained in the design, mixing, installation, and finishing of the porous pavement material. Both porous asphalt and concrete must be mixed and installed much differently than regular asphalt or concrete.
- Exemplary erosion and sediment control during construction and complete site stabilization after construction are essential to prevent clogging of the void spaces within the porous pavement.
- The porous pavement must receive regular, routine vacuuming to remove accumulating solids. At times, nonroutine maintenance may involve cleaning with high-pressure water.
- The entrance to any porous pavement area should have a large sign warning those about to enter that porous pavement is in use. Precautions should include prohibiting vehicles with large amounts of soil on their tires.

## Problems Associated With Infiltration Practices

There have been several concerns regarding the use of infiltration practices, including their propensity to fail, their potential effects on ground-water quality, and their need for maintenance.

Infiltration systems seem to have a very high rate of failure. The author believes, however, that this high failure rate is a reflection of improperly estimated infiltration rates and improper erosion and sediment control during the construction process. A 1990 field survey of stormwater infiltration facilities constructed in Maryland replicated a 1986 field survey, thereby providing data on the performance of infiltration practices after they have been in operation for several years (20). Table 3 summarizes the information from this project.

From Table 3 it can be seen that the overall condition and functioning of infiltration systems declined over time. In 1986, about two-thirds of all facilities were functioning as designed, while in 1990 only about half were. Only 42 percent of the facilities were functioning as designed in both 1986 and 1990, while about 27 percent were not functioning as designed in both years. About 24 percent of the systems were functioning in 1986 but not in 1990, while only 7 percent of those not working in 1986 were working in 1990. Maintenance was needed at more facilities in 1990 (66 percent) than in 1986 (45 percent). Additionally, many facilities (38 percent) that needed maintenance in 1986 still needed maintenance in 1990, while 32 percent of the facilities that did not need maintenance in 1986 did need it in 1990. Only 10 percent of the systems that needed maintenance in 1986 did not need maintenance in 1990. These data indicate that little effort is expended on maintaining the operational capabilities of stormwater management systems.

A second concern about infiltration practices is whether they simply are transferring the stormwater pollution problem from surface waters to ground waters. Harper (14) has shown that stormwater pollutants, especially heavy metals, quickly bind to soil particles, while vegetation is effective in filtering pollutants, thereby minimizing the risk of ground-water contamination. Ground water beneath swales and retention areas located in

Table 3. Comparison of the Operation of Maryland Infiltration Practices

| Type of BMP | 1986 Number of Sites | 1986 Number of Sites Working | 1990 Number of Sites | 1990 Number of Sites Working |
|---|---|---|---|---|
| Basins | 63 | 30 (48%) | 48 | 18 (38%) |
| Trenches | 94 | 75 (80%) | 88 | 47 (53%) |
| Dry wells | 30 | 23 (77%) | 25 | 18 (72%) |
| Porous pavement | 14 | 7 (50%) | 13 | 2 (15%) |
| Swales | 6 | 3 (50%) | 3 | 2 (67%) |
| Totals | 207 | 138 (67%) | 177 | 87 (49%) |

highly sandy soils with low organic content and sparse vegetative cover, however, did show elevated levels of heavy metals down to depths of 20 ft (21).

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# *Stormwater Reuse: An Alternative Method of Infiltration*

**Marty Wanielista**
**University of Central Florida, Orlando, Florida**

## Abstract

Runoff water stored in a wet detention pond can be an asset if it is used to recharge surficial aquifer levels. The recharge can occur directly from the pond by infiltrating the detained water, or the detained water can be irrigated over the watershed. Reuse in the watershed or infiltration at the pond lessens the quantity of water discharged, thus reducing the pollutant mass discharged to surface waters. A benefit of irrigation is a reduction in the use of potable water otherwise used for irrigation.

A mass balance on pond storage volume using rainfall data for select areas in the southeastern United States was completed to determine the percentage of stormwater runoff that can potentially be irrigated or infiltrated for each area as a function of contributing area, runoff coefficient, volume of temporary storage, and irrigation rate. Design curves were developed that relate the efficiency (E), or the percentage of runoff that is irrigated on a yearly basis, to the volume of temporary storage (V) in a reuse pond and the rate of irrigation (R). The design curves, called REV curves, permit the selection of a temporary storage volume and irrigation rate for a given efficiency, runoff coefficient, and geographic area. This paper contains example REV curves and presents simplified uses of the results.

## Introduction

The pollutants associated with stormwater and the volume of stormwater discharges can result in significant impacts to the natural and manufactured environments of any watershed. As watersheds are made more impervious due to paving and other construction activities, the volume of runoff and pollutant mass discharged to surface waters increases relative to predeveloped conditions.

Potential impacts from uncontrolled runoff are loss of freshwater from an area where the rainfall occurred, additional freshwater discharges to estuaries, increased pollutant mass loadings, decreased river base flows, reduced wetland areas, and an economic loss associated with the need to replace discharged freshwater with potable or other waters.

Water policy in the state of Florida requires a performance standard for all stormwater management methods. A stormwater pollutant annual average load reduction of 80 percent for discharges to most waters and of 95 percent for those discharging into outstanding Florida waters (1) are required. Of the currently used stormwater management methods, off-line retention and chemical treatment can achieve the stated pollutant removal efficiencies. Wet detention ponds that discharge to adjacent surface waters, however, do not. If some of the detained water can be used within the watershed and not discharged to surface waters, the wet detention ponds may also meet the standards.

## A Stormwater Reuse Pond

A stormwater reuse pond is proposed to retain runoff water within a watershed and to reduce the mass of pollutants in the discharges to surface water bodies. The difference between a wet detention pond and a reuse pond is the operation of the temporary storage volume. A wet detention pond is designed to discharge the runoff water and possibly some ground water to adjacent surface waters, while a reuse pond is designed to reuse a specific fraction of the runoff volume and not discharge that fraction. In this paper, mathematical relationships are developed between the reuse volume (temporary storage volume), the rate at which stormwater is reused, and the percentage of annual surface runoff that is reused.

The traditional design of pond temporary storage volume for a wet detention pond has been based on the consideration of water quality and uses a design storm. The design storm, however, usually ignores the preceding rainfall record and assumes that there is an antecedent dry period long enough to ensure that the pond is at some control elevation. The usual assumption is a zero temporary storage.

To address the sensitivity of the temporary storage volume to interevent dry periods, long-term rainfall records were used from 25 Florida and seven other southern states' rainfall stations in a model that simulates the behavior of a reuse pond over time. A spreadsheet was used to build a 15-year mass balance for a pond. After each rainfall event, surface runoff and reuse volumes were respectively added to and subtracted from the previous pond storage volume. If the temporary storage volume exceeded the available storage volume, discharge occurred. If the temporary storage volume was less than zero (the permanent pool volume was used for reuse water), supplemental water was used to replenish the pond and maintain the permanent pool. Both the rate of reuse from the pond and the reuse volume were varied. The reuse efficiency, defined as one minus the total volume of surface discharge divided by the total volume of runoff times 100, was calculated for each combination.

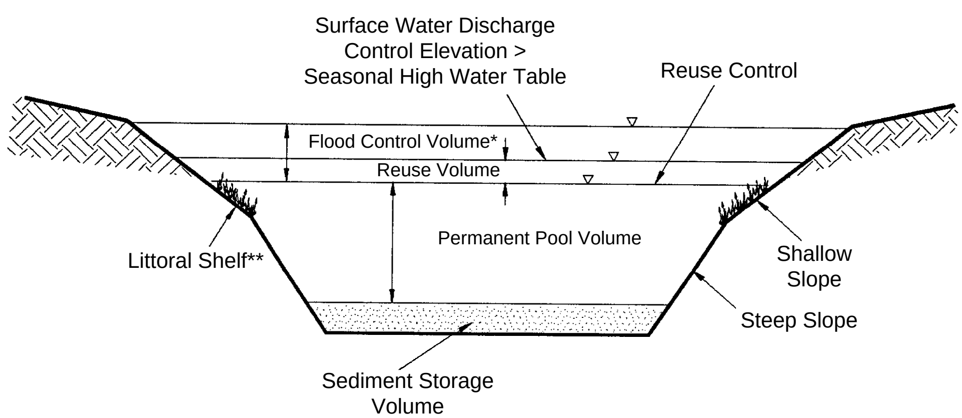
## Simulation of a Reuse Pond

To establish a relationship between the efficiency, the reuse rate, and the reuse volume of a pond, a continuous time model was used to simulate the dynamics of a reuse pond. Continuous models are reported to be most representative (2). The efficiency of the pond, or the percentage of runoff that is reused, was calculated for different reuse volumes and reuse rates. Charts for different regions were produced using the local rainfall records of these regions. The term "model" is used to refer to the basic unchanged equation of the mass balance in which different rainfall records were inserted and reuse volumes and reuse rates were varied. "Simulation" is used to refer to the complete calculations of the model in which volume and rate were defined. There is only one model, while many simulations were done.

Figure 1 depicts a cross section of a typical reuse pond. The sediment storage volume lies at the bottom to receive settled matter. Above this is the permanent pool volume, which provides a minimum residence time for stormwater. The reuse volume (temporary storage volume) is the volume above the permanent pool and below the flood control structure. The flood control volume would typically be above the reuse volume.

The reuse pond differs from a typical detention pond in that instead of the temporary storage volume being depleted by a surface water discharge device (such as a bleed-down orifice in an outlet pipe), it is drawn down by a reuse system and is thus called the reuse volume. A reuse pond may deplete the pond volume below the permanent pool boundary requiring a supplemental volume to maintain this volume. A discharge structure is still necessary for flood control. Common practice should be used for the design of sediment storage, permanent pool, and flood control volumes, and their elevations and side slopes. This paper provides methodology and design criteria for the reuse volume only.

The water level of a typical reuse pond fluctuates during a year. During and following a rainfall event, there is runoff into the pond, and the water level rises to some depth above the permanent pool. If this new water level exceeds the level of the surface discharge control, discharge will occur at some rate until the water level drops back to the elevation of the control structure. The reuse pond volume is incremented daily, removing an amount of water for reuse. If the reuse volume is expended, supplemental water, such as ground water, may be used to maintain the permanent pool volume. This could occur as seepage through the sides of the pond or by mechanical pumping. This scenario was simulated by creating a mass balance for pond operation.




* Can be measured above permanent pool; however, some regulatory agencies measure above the reuse volume.
** The reader should consult local water management districts and other regulatory agencies to determine specific geometric and littoral zone design requirements.

**Figure 1. Schematic of a stormwater reuse pond.**

## The Model

The model is based on the continuity equation

INPUTS - OUTPUTS = $\Delta$S. (Eq. 1)

If all potential water movements are considered, a complete hydrologic balance may be expressed in volume units as

$$R_E + G + P \pm F - R - D - ET = \Delta S, \quad \text{(Eq. 2)}$$

where

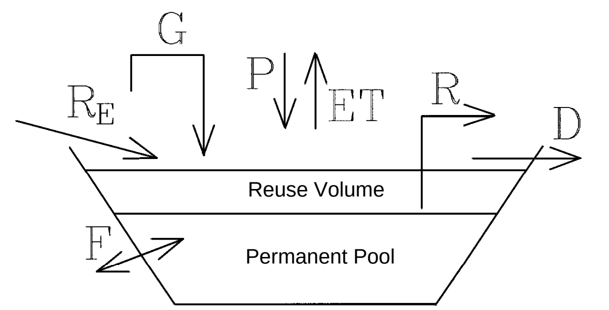
$R_E$ = rainfall excess or runoff volume
G = supplemental water (ground water)
P = precipitation directly on the pond
F = water movement through the sides of the pond
R = reuse (infiltration)
D = discharge
ET = evapotranspiration
S = storage in pond

In Florida, the average evapotranspiration rate for a pond is generally equal to the average precipitation on the pond in a 1-year period (approximately 50 in.). Additionally, evaporation data are only available in mean monthly rates compared with the daily time step of the model, making the estimate of evaporation potentially inaccurate. These parameters were dropped from the mass balance. Also, because of its complexity, the flow of ground water through the sides of the pond was assumed to equal zero, and Equation 2 was further simplified to

$$R_E + G - R - D = \Delta S. \quad \text{(Eq. 3)}$$

For Florida modeling purposes, there were two inputs, runoff and supplement, and two outputs, reuse and discharge (Figure 2). Runoff was established from known precipitation and watershed data. The reuse rate was a controlled variable. Both supplemental water and discharge were functions of the water level of the pond, or the storage volume. Because ground-water movement was assumed to equal zero, supplemental water is considered as that which is pumped into the pond mechanically. Supplement occurs at a rate necessary to maintain the permanent pool; the maximum required rate would equal that of reuse. Because potential storage capacity is being constantly eliminated by supplement, this may be considered as being conservative. With the previous simplifications, the actual pond may be simulated by the model.

The calculations for each simulation were done using Quattro Pro, an electronic spreadsheet. The top and bottom calculations and input data for one simulation can be seen in Figure 3. The columns of the upper portion of the simulation are the incremental registers of




$$R_E + G + \not{P} \pm \not{F} - R - D - \not{E}T = \Delta S$$

$$R_E + G - R - D = \Delta S$$

**Figure 2. Summary of mass balance of reuse pond, simplified for Florida conditions.**

the various parameters, which are labeled along the top. Each of these variables is defined as follows:

| | |
|---|---|
| EVENT | A distinct rainfall occurrence; for computational purposes, each day of a multiday rainstorm is considered a separate event. |
| DATE | The date on which an event occurs. |
| DRY | The dry period separating rainfall events (days); if events occur on consecutive days there are no dry days. This value is not used in the basic model but is needed for the sensitivity analysis of the discharge potential. |
| RAIN | The amount of rainfall recorded during each event (inches). This information was taken directly from National Oceanic and Atmospheric Administration (NOAA) rainfall data. |
| RUNOFF | The amount of runoff that enters the pond during an event (inches). |
| REUSE | The amount of water reused during the day of an event and the dry days following the previous event (inches); the rate of reuse remains constant during a single simulation. |
| DISCHARGE | |
| Potential: | The potential amount of discharge for an event (inches); the amount that could, if necessary, physically discharge during the time since the previous event. This was established as 2 in./day over the equivalent impervious area (EIA). |

ORLANDO RAINFALL STATION (May 1974 - Dec. 1988) Volume = 3 in, Rate = 0.2 in/day

| EVENT | DATE | DRY Days | RAIN In. | RUNOFF In. | REUSE In. | DISCHARGE Poten. | DISCHARGE Actual | SUPLMNT In. | NET In. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 04-May-74 | | | | | | | | 0 |
| 1 | 05-May-74 | 0 | 0.12 | 0.12 | 0.2 | 2 | 0 | 0.08 | 0.00 |
| 2 | 06-May-74 | 0 | 0.77 | 0.77 | 0.2 | 2 | 0 | 0.00 | 0.57 |
| 3 | 07-May-74 | 0 | 0.04 | 0.04 | 0.2 | 2 | 0 | -0.00 | 0.41 |
| 4 | 08-May-74 | 3 | 0.33 | 0.33 | 0.2 | 2 | 0 | 0.00 | 0.54 |
| 5 | 12-May-74 | 1 | 0.15 | 0.15 | 0.8 | 8 | 0 | 0.11 | 0.00 |
| 6 | 14-May-74 | 0 | 0.11 | 0.11 | 0.4 | 4 | 0 | 0.29 | 0.00 |
| 7 | 15-May-74 | 0 | 0.46 | 0.46 | 0.2 | 2 | 0 | 0.00 | 0.26 |
| 8 | 16-May-74 | 0 | 0.07 | 0.07 | 0.2 | 2 | 0 | 0.00 | 0.13 |
| 9 | 17-May-74 | 5 | 0.23 | 0.23 | 0.2 | 2 | 0 | 0.00 | 0.16 |
| 10 | 23-May-74 | 3 | 0.35 | 0.35 | 1.2 | 12 | 0 | 0.69 | 0.00 |
| 11 | 27-May-74 | 4 | 0.06 | 0.06 | 0.8 | 8 | 0 | 0.74 | 0.00 |
| 12 | 01-Jun-74 | 0 | 1.19 | 1.19 | 1 | 10 | 0 | 0.00 | 0.19 |
| 13 | 02-Jun-74 | 0 | 0.07 | 0.07 | 0.2 | 2 | 0 | 0.00 | 0.06 |
| 14 | 03-Jun-74 | 6 | 0.05 | 0.05 | 0.2 | 2 | 0 | 0.09 | 0.00 |
| 15 | 10-Jun-74 | 0 | 2.19 | 2.19 | 1.4 | 14 | 0 | 0.00 | 0.79 |
| 16 | 11-Jun-74 | 2 | 0.18 | 0.18 | 0.2 | 2 | 0 | 0.00 | 0.77 |
| 17 | 14-Jun-74 | 0 | 0.05 | 0.05 | 0.6 | 6 | 0 | -0.00 | 0.22 |
| 18 | 15-Jun-74 | 1 | 0.54 | 0.54 | 0.2 | 2 | 0 | 0.00 | 0.56 |
| 19 | 17-Jun-74 | 6 | 0.09 | 0.09 | 0.4 | 4 | 0 | 0.00 | 0.25 |
| 20 | 24-Jun-74 | 0 | 0.95 | 0.95 | 1.4 | 14 | 0 | 0.20 | 0.00 |
| 21 | 25-Jun-74 | 0 | 1.07 | 1.07 | 0.2 | 2 | 0 | 0.00 | 0.87 |
| 22 | 26-Jun-74 | 0 | 3.47 | 3.47 | 0.2 | 2 | 0 | 0.00 | 4.14 |
| 23 | 27-Jun-74 | 0 | 1.89 | 1.89 | 0.2 | 2 | 1.14 | -0.00 | 4.69 |
| 24 | 28-Jun-74 | 1 | 3.36 | 3.36 | 0.2 | 2 | 1.69 | 0.00 | 6.16 |
| 25 | 30-Jun-74 | 0 | 0.17 | 0.17 | 0.4 | 4 | 3.16 | 0.00 | 2.77 |
| 26 | 01-Jul-74 | 0 | 0.12 | 0.12 | 0.2 | 2 | 0 | -0.00 | 2.69 |
| 27 | 02-Jul-74 | 0 | 0.88 | 0.88 | 0.2 | 2 | 0 | 0.00 | 3.37 |
| 1386 | 23-Dec-88 | 4 | 0.04 | 0.04 | 1.4 | 14 | 0 | 1.36 | 0.00 |
| 1387 | 28-Dec-88 | | 0.05 | 0.05 | 1 | 10 | 0 | 0.95 | 0.00 |
| | Summation: | | 706.88 | 706.88 | 1070.40 | | 75.72 | 439.24 | |

% Discharged = Total Discharge/Total Runoff = 10.71%

% Reused = 1 - Total Discharge/Total Runoff = 89.29%

Inputs:

| | | | | |
|---|---|---|---|---|
| Runoff: | 706.88 in. | | Inputs | 1146.12 in. |
| Supplement: | 439.24 in. | | - Outputs | -1146.12 in. |
| | 1146.12 in. | | Storage | 0.00 in. |

Outputs:

| | |
|---|---|
| Reuse: | 1070.40 in. |
| Discharge: | 75.72 in. |
| | 1146.12 in. |

**Figure 3. Example of computer model using rainfall data from Orlando, Florida.**

| | |
|---|---|
| Actual: | The amount that does discharge during an event (inches); depends on the water level of the pond but is restricted to the potential discharge. |
| SUPLMNT | The amount of water needed between events to maintain the permanent pool volume (inches). |
| NET | The amount of water above the permanent pool recorded at the end of each event (inches). |

Every day in which a rainfall event takes place represents one line in the simulation. This is the fundamental time step of the model. All inputs and outputs occur during this 24-hour period. At the end of the period, the net storage value of the pond is calculated. From this value, decisions are made concerning discharge and supplement. The process then repeats itself.

The 15-year totals for rain, runoff, reuse, actual discharge, and supplement are calculated as shown in Figure 3. From these values, the efficiency, or the percentage of runoff reused, can be determined for a particular simulation. The efficiency is equal to one minus the volume of water that is discharged divided by the volume of runoff times 100. The percent discharged, the volume of water discharged divided by the volume of runoff, is also calculated. The percent reused plus the percent discharged equals 100.

At the bottom of Figure 3 is a summary of the mass balance for the entire record. Both the inputs and outputs are listed and totaled. The difference between the inputs and outputs, labeled “Storage,” is compared with the final value for NET. The values should be identical. This is used primarily to check the calculations.

This single model was used to predict the behavior of a reuse pond subjected to the rainfall record of 32 different locations in the southeastern United States. Previously, one location in Florida was reported (4). To simulate a pond in a particular region, the rainfall record of that region was inserted into the DATE and RAIN columns of the model. The model was then lengthened or shortened to match the span of the rainfall record. Otherwise, no changes were made to the model. By using one model and varying only the rainfall record, the consistency of the simulations was assured.

### *Length of Rainfall Record*

An investigative question that arises when examining the random behavior of rainfall is how large a record must be to accurately represent the meteorological characteristics of a region. In other words, how many years of rainfall data must be used to estimate the ultimate dynamics of the pond? Obviously, the greatest accuracy can be obtained by using the most data. But the incremental benefit of each additional unit of data diminishes so that there is a point beyond which using more is no longer reasonable. This is the limit for investigation.

Twenty-four individual simulations were run for the Moore Haven and Tallahassee stations using, first, 1 year of rainfall data (1988) and then incrementally adding the next previous year to the rainfall record. The yearly efficiencies for several combinations of reuse volumes and reuse rates were recorded. As expected with only a few years of data, the average yearly efficiencies fluctuated widely but then leveled out as more years of data were added. As the size of the database increased, each additional year had less impact. Beyond 15 years, there was very little change in the average annual estimate.

### *Volume Units*

Runoff, discharge, reuse, supplement, and net storage are volumes of water that are expressed in units of inches. Volumes are commonly expressed as inches over a defined area and, likewise, the parameters of this model are based on a variable unit area that the user defines. Rates are merely volumes delivered over a period and thus can be expressed in the same manner. This unit area is the EIA of the watershed or the product of the runoff coefficient and the contributing watershed area. The volumetric unit of inches on the EIA is a way in which the results are generalized for any runoff coefficient and contributing area. Once the EIA is known, the values can be converted to more practical units using simple conversions.

## Model Output

The basic function of the model is to determine a relationship between the reuse rate, the reuse volume, and the efficiency. This was done by varying the reuse rate and the reuse volume, then calculating the efficiency. Thus, a simulation was done for each combination of reuse rate and reuse volume. The reuse volumes considered varied between 0.25 and 7.0 in. on the EIA. The reuse rates varied between 0.04 and 0.30 in./day on an area equivalent to the EIA. The respective efficiencies are shown as fractions. The results are presented in chart form as shown in Figure 4. The ultimate functional product of the reuse pond model is the rate-efficiency-volume (REV) chart. Wanielista et al. (5) presents the REV charts for all of the 25 locations in Florida for which accurate and long-term rainfall data were available. Individual REV charts are specific to geographical regions with similar meteorological characteristics.

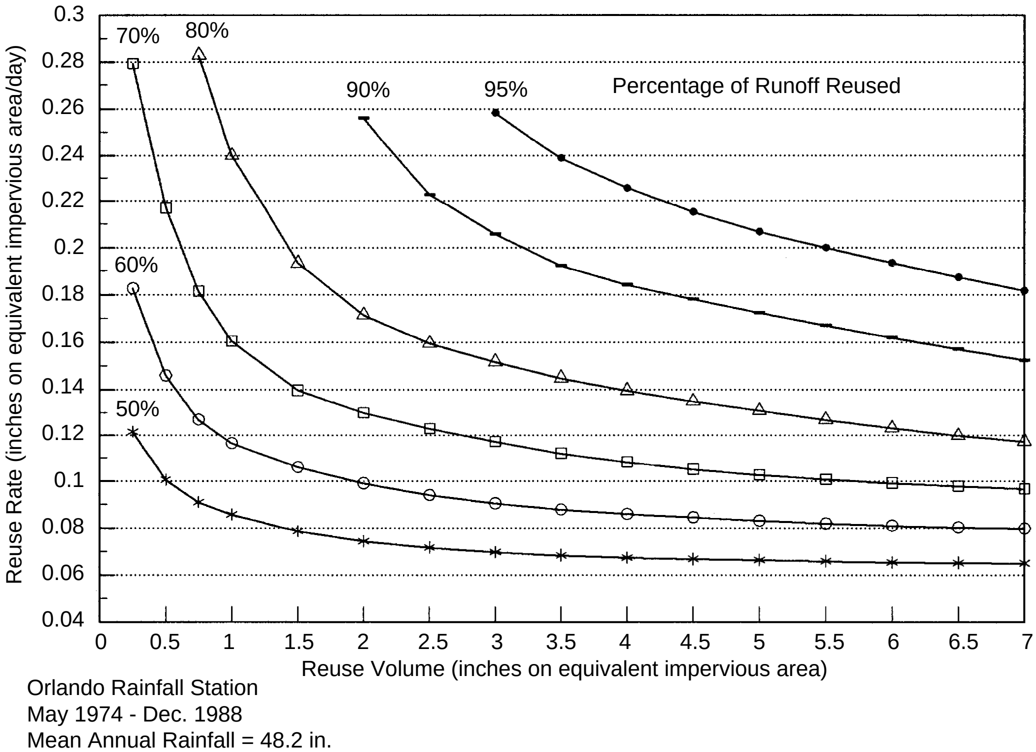



**Figure 4. REV chart for Orlando, Florida.**

## *Use of the REV Charts*

REV charts relate the reuse rate, the efficiency, and the reuse volume of a pond. Recommended irrigation rates for Florida are between 0.38 in./week in the winter to 2.25 in./week in the summer (6). Information concerning any two of these three variables is necessary for the determination of the third. The use of a REV chart requires an understanding of the concept of the EIA. The units of both the reuse rate and the reuse volume are based on this area. A REV chart is specific for an area, and the accuracy of the predictions are related to the accuracy of the input data. The REV charts of this paper have been placed in a computer program that reduces the possibility of calculation errors (7).

The efficiency is defined as the average percentage of runoff that is reused over a period, specifically 15 years. A pond that discharges to surface waters 10 percent of the runoff that flows into it must reuse the remaining and so is 90 percent efficient. It may sometimes be desirable to determine the efficiency of an existing pond. More often it will be necessary to achieve a required efficiency established by local regulations, thus making the efficiency one of the known values. On every REV chart, there is a curve for each of the following efficiency levels (in percentage): 50, 60, 70, 80, 90, and 95.

## *Examples of Direct Use*

**Example 1**

A watershed in Orlando must reuse 80 percent of the annual runoff from a 10-acre impervious area. The pond area is included in the impervious area. The maximum reuse storage volume available for the pond is equal to the runoff from a 3-in. rainfall event. At what rate must the runoff be reused?

Because the entire watershed is impervious, the EIA is equal to 10 acres. Because runoff equals rainfall on impervious areas, the storage volume is equal to 3 in. on the EIA. The reuse rate is a function of the efficiency and the reuse volume:

R = f (E,V)
= f (80%, 3 in.)
= 0.152 in./day

By referring to the Orlando REV chart (Figure 4), the necessary reuse rate is estimated at 0.152 in./day on the EIA. The rate and volume can be expressed in other units:

$$V = 3 \text{ in.} \times \text{EIA} \times \frac{10 \text{ ac}}{\text{EIA}}$$

$$= 30 \text{ ac–in.} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 109{,}000 \text{ ft}^3$$

and

$$R = 0.152 \frac{\text{in.}}{\text{day}} \times \text{EIA} \times \frac{10 \text{ ac}}{\text{EIA}}$$

$$= 1.52 \frac{\text{ac–in.}}{\text{day}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 5{,}520 \frac{\text{ft}^3}{\text{day.}}$$

**Example 2**

An apartment complex located in Tallahassee needs to reuse 90 percent of the runoff from its parking lots. The EIA is equal to the directly connected impervious area and is 4 acres. The complex wants to use 0.26 in. of water per day over the EIA. What must the reuse volume be to maintain these conditions?

From the REV chart for Tallahassee (Figure 5), the required reuse volume is determined to be 3.5 in. on the EIA:

$$V = f\,(E,R)$$
$$= f\,(90\%,\ 0.26 \text{ in./day})$$
$$= 3.5 \text{ in.}$$

Again, the volume and rate can be expressed in other units:

$$V = 3.5 \text{ in.} \times \text{EIA} \times \frac{4 \text{ ac}}{\text{EIA}}$$

$$= 14 \text{ ac–in.} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 50{,}800 \text{ ft}^3$$

and

$$R = 0.260 \frac{\text{in.}}{\text{day}} \times \text{EIA} \times \frac{4 \text{ ac}}{\text{EIA}}$$

$$= 1.04 \frac{\text{ac–in.}}{\text{day}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 3{,}780 \frac{\text{ft}^3}{\text{day.}}$$

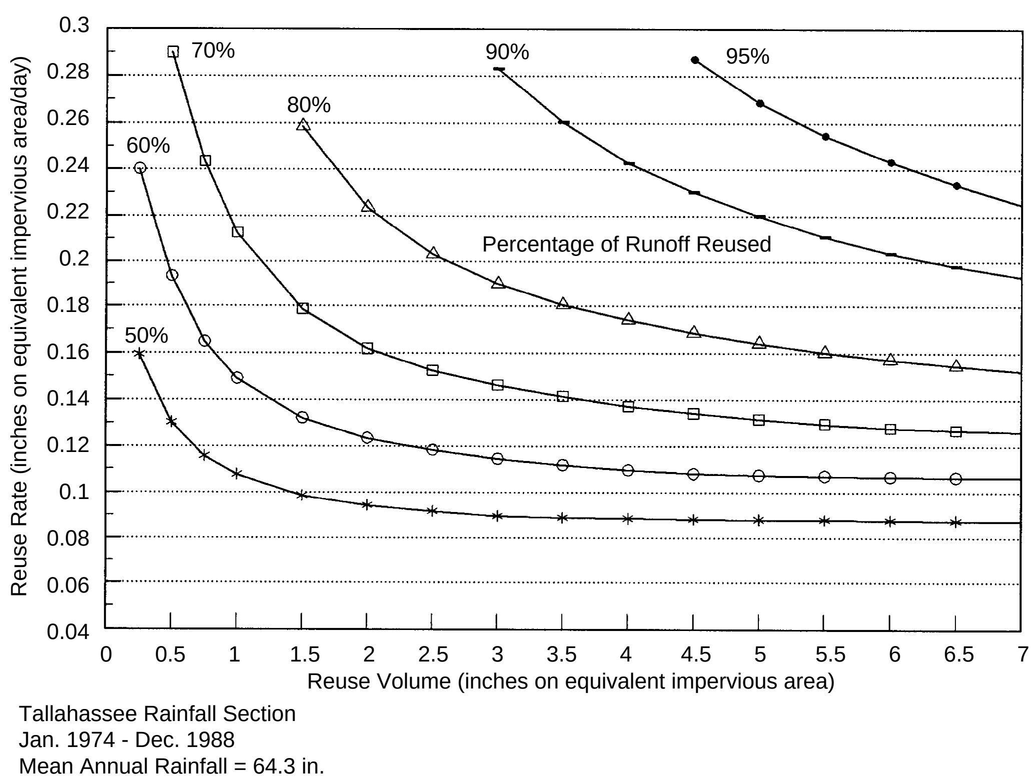



**Figure 5. REV chart for Tallahassee, Florida.**

The previous examples illustrate the most simple application: the watershed being impervious and the volume and rate given in terms of the EIA. Much more complex design problems, however, can be solved using the same technique. The following steps can be used in any design situation:

1. Select the appropriate chart.
2. Compute the EIA of the watershed (EIA = contributing area x effective C).
3. Determine known variables in terms of the EIA.
4. Reference the chart to obtain a solution.
5. Convert the answer to desired units.

## Evaporation and Rainfall on Pond

One of the initial simplifications of the pond mass balance was the assumption that the mean annual evaporation from the pond is equal to the mean annual rainfall on the pond. The evaporation totals in the Southeast may range from 30 to over 60 in./yr. Precipitation rates range from 37 in./yr in Key West to 64.5 in./yr in Tallahassee.

While evaporation and direct rainfall rates are based on the size of the pond, all other model parameters were based on the EIA. Therefore, a ratio was established between the size of the pond and the EIA. Because detention ponds usually require no more than 5 percent of the total area of the watershed, depending on the impervious area, a conservative estimate of pond area to a completely impervious area was chosen as 1:10. As an example, a 1-in. rainfall event, through direct precipitation, would add 1 in. of rainfall to the pond or 0.10 in. over the EIA.

Evaporation data were obtained from NOAA Climatological Data publications for the years 1985 through 1989. Because the locations of climatological stations match those of precipitation stations in only a few instances, evaporation data from nearby stations were used with selected model locations. Evaporation data from Lisbon and Lake Alfred were introduced into the models of Orlando and Parrish, respectively. The evaporation data were available in monthly pan evaporation totals. Fifteen years of records were used and converted to surface water evaporation rates by multiplying by a pan coefficient. The mean annual total evaporation for the two locations is 56.46 in. for Lake Alfred and 41.07 in. for Lisbon.

The evaporation function was added to the models by distributing evaporation depths in inches for each time interval. The amount of evaporation for each interval is the product of the number of days in that interval and mean daily evaporation rates for the month. To ensure the assumed distribution did not affect the total evaporation volume, the mean annual evaporation volumes for the 15-year simulations were compared with the mean volumes obtained from NOAA. The totals were almost identical.

To use the REV charts, rainfall on the pond must be included in the calculation of the EIA. When the area of the pond (approximated at 15 percent of the EIA) was added to the EIA, the pond reuse volume increased, and for a fixed reuse rate the average annual efficiency increased by at least 2.5 percent. Because rainfall on the pond reflects an impervious condition (all rainfall yields rainfall excess), it must be added to the EIA while maintaining consistent units (depth on an impervious area).

## Recommendations

A mathematical mass balance model can be developed to simulate the operation of a stormwater reuse pond. This can be done for areas that have daily rainfall data available for a significant period, about 15 years.

The reuse of stormwater within a watershed from which it came should be encouraged and in some areas required. Reuse ponds can be designed to conserve water within a watershed and to reduce the mass of pollutants entering the surface waters.

The effective impervious area for a watershed should include the area of the pond when using the REV curves. The effective impervious area calculation is necessary for the use of the REV curves. More than one REV curve for a location is expressed in a figure called a REV chart.

For an average annual pollutant mass removal of 80 percent in a wet detention pond, at least 50 percent of the runoff volume should be reused when the REV charts are used for design. For a 95 percent annual pollutant mass removal, at least 90 percent of the runoff volume should be reused. The reuse percentages assume a wet detention pond will remove an average 60 percent of the incoming runoff pollution mass annually before surface discharge, which may overestimate the actual efficiency.

The reuse of stormwater is both an environmentally and economically sound management practice. The current common practice is to release stormwater to adjacent surface waters from detention ponds using weirs and orifices. Frequently, if not all the time, this detained volume of water is greater than the volume of water released from the land in its natural condition. Some fraction of this detained water can be reused within the watershed to 1) irrigate open areas, 2) recharge ground water, 3) supplement water used for certain industrial purposes, 4) enhance and create wetlands, and 5) supply water for agricultural users.

Currently, the most popular reuse method has been the irrigation of relatively open spaces, for example, golf courses, cemeteries, recreation areas, citrus groves, and common areas of apartment complexes. The primary reason for these reuse systems is economics. Many irrigation systems use treated ground water. An alternative to the use of ground water is detained stormwater. Treated ground water cost about $1.00/thousand gallons. A golf course of 100 acres using treated ground water at a cost of $1.00/thousand gallons and irrigating at 2 in./wk would pay almost $300,000/yr for the irrigation. Using detained stormwater, the irrigation system yearly cost could be less than $40,000.

In this paper, continuous modeling for reuse ponds was completed and was based on a mass balance using area-specific rainfall data to develop design criteria for stormwater reuse ponds. The design procedure relates pond temporary storage (reuse volume) to reuse rate and a percent reuse of the runoff water and is expressed as a REV curve. Also, mathematical equations for the curves have been computer coded.

The REV curves can be used for various watershed sizes or runoff coefficients. They may be used to determine the reuse rate, the reuse volume, or the efficiency of a pond. Supplemental water needs in a hydrologic balance also can be estimated. The REV charts presented in this paper could facilitate the rational planning of stormwater reuse systems.

## Acknowledgments

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# Use of Sand Filters as an Urban Stormwater Management Practice

**Earl Shaver**
**State of Delaware, Department of Natural Resources and Environmental Control,**
**Dover, Delaware**

## Background

As our recognition of the need for stormwater control, from both quantity and quality perspectives, has increased, efforts to develop strategies and practices to address stormwater runoff have emerged all over the country. Many of these efforts have been developed on a state or local level depending on the specific issues that motivated program development.

The concerns over stormwater control and strategies for dealing with stormwater are now international in scope. Society as a whole needs to learn about what individuals have already accomplished to allow for evolution of control strategies and individual practices. Efforts under way at the state level (in Delaware, Florida, Maryland, South Carolina, and Washington) and at the municipal level (in Austin, Texas; Washington, DC; and Alexandria, Virginia) provide some hands-on knowledge regarding the programs and types of stormwater control practices that have been used successfully.

The intent of this paper is to discuss stormwater control practices, in particular, filtration systems. Experience with stormwater control ponds and infiltration systems has led to considerable knowledge about these methods, but interest is increasing in the use of sand filters in several locations around the country for stormwater treatment. Use of these systems will expand as national efforts addressing stormwater control are implemented.

## Existing Efforts in the Use of Sand Filter Systems

The first interesting point is the way that sand filter systems have been used historically around the country. These systems are being used for onsite and regional control, as well as for water quality control only and for both water quality and water quantity control.

### *Austin, Texas*

The city of Austin has pioneered the use of sand filters for stormwater treatment. Other areas have experimented over the years with sand filters, but Austin has made a long-term commitment to their use and evolution. The design standards for sand filters have evolved based on performance and maintenance considerations.

Sand filters are used on site and on a regional basis (usually less that 50 acres of drainage), and the filters are sized to accept and treat the first half-inch of stormwater runoff from the contributing drainage area (1). They are frequently used in conjunction with a stormwater detention basin, which provides for control of larger storms from a water quantity perspective. Good water quality data for the performance of these systems have resulted, which indicates that sand filters can be very effective at pollutant removal.

### *Washington, DC*

Sand filter use is based on a design standard developed by the Stormwater Management Branch of the Department of Consumer and Regulatory Affairs. The sand filter system design is based on whether water quantity is a concern in addition to water quality on a specific site. Washington, DC, has a combined sewer system, and sites that discharge into a combined sewer system must design their sand filters to provide for peak control of the 15-year storm. If only water quality is an issue, a design procedure is established based on the degree of site imperviousness. For water quality control alone, storage requirements are between 0.3 and 0.5 in. of runoff per acre (2). The Stormwater Management Branch is initiating a monitoring program to determine the performance of the sand filters.

### *State of Delaware*

Delaware has developed a sand filter design system based on the Austin design but that serves for water quality control only. It is intended for sites where stormwater runoff, only from impervious areas, may drain to the sand filter. The sand filter is designed to accept and treat the first inch of stormwater runoff and is used as either a "stand alone" practice or in conjunction with another practice, such as an infiltration practice (3). Where infiltration practices are used, the sand filter provides pretreatment of the runoff to reduce premature clogging of the infiltration practice. At this time, design performance is not being monitored, but achieving an 80-percent reduction in suspended solids is considered an acceptable practice as required under the statewide stormwater management law.

### *Alexandria, Virginia*

The city of Alexandria has developed a design manual that supplements the northern Virginia BMP handbook (4). The Alexandria supplement details the design requirements of "no net increase" in pollutant loading for new development and a 10-percent reduction in pollutant loading at site redevelopment locations. To achieve these goals, phosphorus was accepted as a "keystone" pollutant for design purposes. The Alexandria supplement provides information on a number of different sand filter design procedures and is probably the single best compilation of information relating to design procedures developed in areas such as Austin, Delaware, and Washington.

### *Other Areas and Efforts*

The only other procedure that is more experimental (although, in reality, they all still are) is the peat-sand filter developed by the Washington Council of Governments. This procedure is a variation of the traditional sand filter design that uses peat as a medium for enhanced nutrient reduction. The State of Washington has recently completed a stormwater design manual that presents a sand filter design based on the Austin system.

## Discussion

Sand filters represent an emerging technology with significant potential for evolution in coming years. The procedure developed for the State of Delaware was intended for use on small sites where overall site imperviousness was maximized. Examples of these sites would be fast food restaurants, gas stations, or industrial sites, where space for retrofitting is not readily available. Another emphasized use for sand filters is as a pretreatment system for stormwater infiltration practices. Infiltration practices are very susceptible to clogging by particulates, and sand filters could provide an effective means to reduce particulate loading and to block oil and grease from entry into infiltration systems.

Sand filters are especially appropriate for highway systems where site conditions and right-of-ways limit the types of feasible stormwater treatment practices. Sand filter systems generally have lower maintenance needs than infiltration practices have, so their use appeals to highway officials if the costs can be made reasonable.

If the sand filter is moved to the edge of the parking lot or roadway, where structural strength is not as important, the system can be installed at significantly lower cost. The City of Alexandria has developed a variation of the Delaware approach where the sand filter is behind curb openings. In addition, increasing the head over the filter can increase the time between required maintenance of the filter, thus lowering the system's operation and maintenance costs. Consideration should be given to placing stone over the sand to prevent scour of the sand as water drops on the filter, in addition to increasing the overall depth of the sand to improve performance.

The design procedure developed for use in Delaware is meant as guidance and can be modified or enhanced as needed depending on specific site conditions. The practice as presented may be used in the middle of a parking lot, where concrete and grate strength are established, so that automobiles or trucks could travel over the system. Consultants have taken that design standard literally, which has made construction costs extremely high.

Any one of these systems could be modified or improved with proper engineering. Conversations have started with different manufacturers to see if sand filter units could be prefabricated which would reduce the overall cost of installation. The use of sand filters will dramatically increase if construction costs are reduced.

## Conclusion

Sand filters have a strong potential for becoming an effective tool for stormwater treatment, but engineering expertise is necessary to improve performance and cost. With proper maintenance and in conjunction with other practices, sand filters can assist in water quality protection. They also have potential in arid regions, where more conventional practices such as wet ponds are not feasible.

We live in an era where our desires and mandates for clean water exceed our abilities to actually protect our aquatic resources when structural controls are considered as the only method of stormwater control. The term "treatment train" is certainly a concept that must be expanded if resource protection is to be realized. Sand filters are one car of the "treatment train," but the overall train must include many different considerations. Ultimately, land use must be a consideration in overall site stormwater planning, and considerations of roadway widths, curbing, and site compaction and utilization must be flexible depending on individual site needs. Why does a residential street have to be wide enough for a fire engine to turn around in? We need to question basic planning assumptions with respect to resource protection, and to evaluate whether a specific design requirement is necessary in light of that requirement's impact on our natural resources. Otherwise, we need to recognize and accept the fact that a decline in quality and productivity of our resources will occur.

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# *Application of the Washington, DC, Sand Filter for Urban Runoff Control*

**Hung V. Truong**
**DC Environmental Regulation Administration, Washington, DC**
**Mee S. Phua**
**University of DC, Washington, DC**

## Abstract

Conventional infiltration systems are frequently used for water quality control of urban runoff. These types of urban best management practices (BMPs), however, may adversely affect ground-water quality through the migration of pollutants into ground-water aquifers. Additionally, these BMPs may not be feasible in high-density urban areas because of the large land areas required for their installation.

To address these problems, this paper presents an alternative solution: to replace conventional infiltration BMPs with the confined, underground sand filter water quality (SFWQ) control structure. Over 70 of these structures have been installed in Washington, DC, since 1988.

The Washington, DC, underground sand filter is a gravity flow system consisting of a concrete structure with three chambers. It is designed to provide quality control for the first ½ in. of runoff. The first chamber performs pretreatment of stormwater runoff by removing floating organic material such as oil, grease, and tree leaves. The second chamber is the filter chamber (process chamber) and optimally contains a 3-ft filter layer. The filter layer consists of gravel, clean sand, and geotextile filter fabric. At the bottom of the filter is a subsurface drainage system of polyvinyl chloride perforated pipes in a gravel bed. The third chamber is a discharge chamber that collects flow from the underdrain pipes.

The SFWQ structure may vary in size and shape. The depth can range from 8 to 10 ft depending on the final grading of the site.

## Introduction

Urbanization resulting in surface- and ground-water contamination is a serious and constant threat to water quality. In turn, poor water quality is an undesirable economic burden on taxpayers. Because of the extremely high cost involved in restoring contaminated surface and ground water, prevention seems to be the only economical course of action to protect natural water systems.

To regulate and provide protection for surface- and ground-water systems, the federal government passed the Clean Water Act. As part of this effort, the District of Columbia enacted stormwater management regulations (DC Law 5-188, section 509-519) in January 1988. These regulations require new developments and redevelopments to control nonpoint source pollution transported from construction sites by urban runoff, using best management practices (BMPs) or best available technologies (BATs).

Infiltration devices are the most frequently used BMPs for controlling stormwater runoff in urban areas. These conventional BMPs have limitations, however, due to soil and site-specific constraints. These BMPs may also adversely affect ground water through the migration of pollutants into ground-water aquifers. Additionally, conventional infiltration systems may not be feasible in an urban environment because of the large land areas required for their installation. In an effort to mitigate these problems, an alternative design is outlined in this paper to replace the conventional infiltration BMPs, where applicable. This alternative system is called the confined sand filter water quality (SFWQ) structure and is illustrated in Figure 1. The system uses multiple filter layers combined with a moderate detention time to filter the suspended pollutant particles and hydrocarbons from urban runoff. A multiple-layer filter was chosen because it has proven to be more effective than a single-layer filter design.

## Background

Infiltration practices have been widely used to improve the quality of urban stormwater runoff. Several limitations, however, are associated with the use of conventional

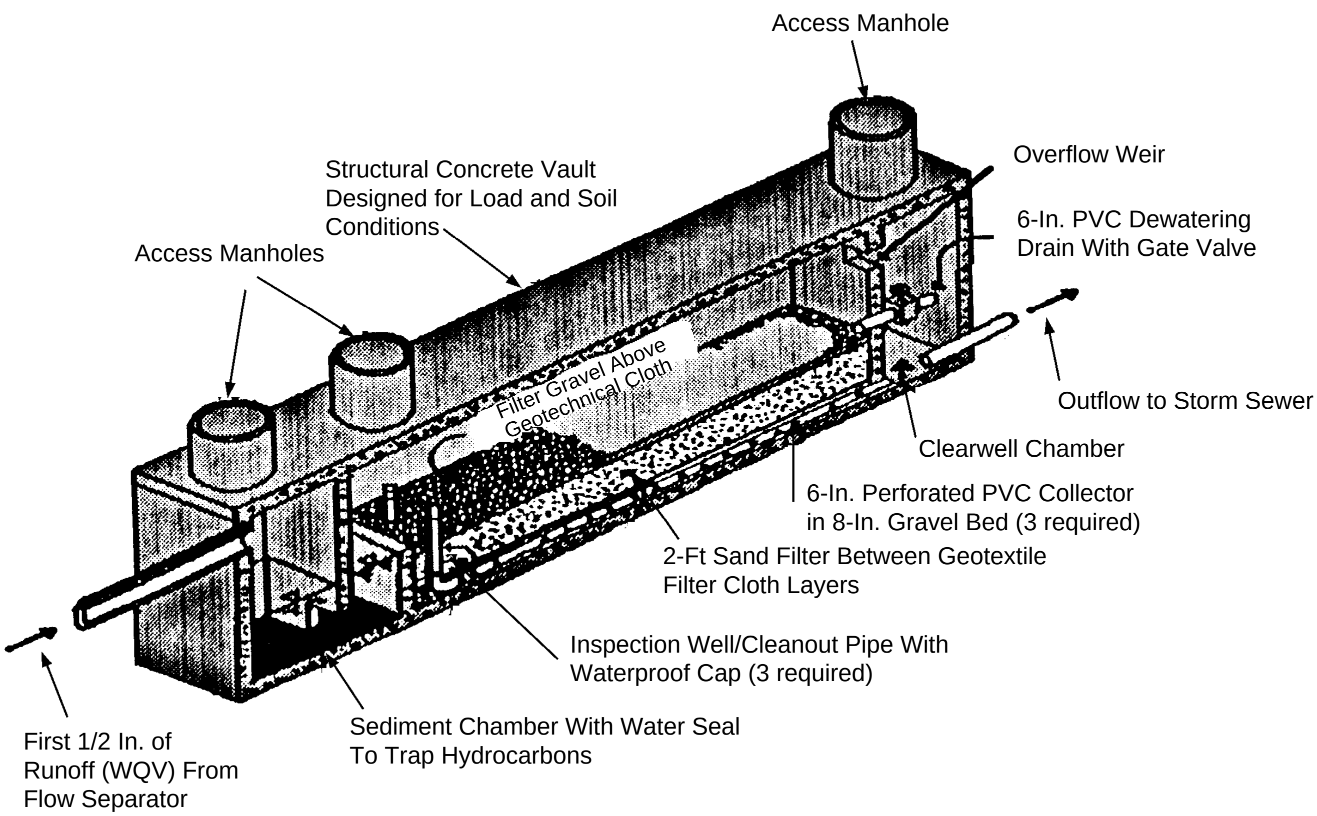


**Figure 1. DC three-dimensional sandfilter centerline cutaway (source: District of Columbia).**

infiltration systems. According to several studies (1-3), the practice of infiltration may have a negative impact on ground-water quality. In addition, infiltration practices are only recommended for sites with soil infiltration rates higher than 0.27 in./hr and with a clay content of less than 30 percent. Recently, a study by the Metropolitan Washington Council of Government (MWCOG) shows that over 50 percent of the infiltration trenches installed in the Metropolitan Washington region either partially or totally failed within the first 5 years of construction (4). Research has also found that clogging may occur in infiltration trenches and is also very common in other infiltration systems. In surface systems, clogging is most likely to occur near the top of the structure, between the upper layer of stone and the protective layer of filter fabric. For underground infiltration systems, clogging is likely to occur at the bottom of the structure, at the filter fabric, and at the soil interface.

Restoration of both surface and underground infiltration systems is tedious and very costly, requiring the removal of the vegetation layer, top soil, protective plastic layer, stone aggregate, and filter fabrics. If the surface layer is pavement or concrete, the rehabilitation effort becomes even more difficult and expensive. Conventional infiltration systems also require relatively large areas of land for their installation; therefore, this family of BMPs is not feasible due to the high cost of land in an urban environment.

## Design Rationale

Whenever a liquid containing solids in suspension is placed in a relatively quiescent state, solids having a higher specific gravity than the liquid settle, while those having a lower specific gravity rise. The design of the SFWQ structure uses the one-dimensional “falling head test” in Darcy’s Law for calculating the head loss of fluid flow through a multiple-layer filter medium to treat stormwater runoff. The design uses various media layers with different permeabilities to intercept pollutant particles as fluid flows vertically through the filter layers. This principle can be used to accelerate the removal of pollutants by increasing the residence times of stormwater runoff, and to facilitate the filtering process in the filter chamber. The SFWQ structure also utilizes Stoke’s Law for terminal falling velocities of individual particles in allowing time for particles to settle out of stormwater runoff. The average detention time of this system ranges from 6 to 8 hr for an optimal design consideration.

## Functional and Physical Description

The SFWQ structure is a gravity flow system consisting of three chambers. The facility may be precast or cast-in-place. The first chamber (same as water quality inlet) is a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. The chamber has a submerged weir leading to the second chamber (filter chamber) and may be designed with a flow splitter or with a bypass weir if the system is for off-line storage, as illustrated in Figure 2.

The second chamber contains 3 ft of filter material consisting of gravel, geotextile fabric, and sand, and is situated behind a 3-ft weir. At the bottom is a subsurface drainage system consisting of a parallel polyvinyl chloride (PVC) pipe system in a gravel bed. A dewatering valve is at the top of the filter layer for maintenance purposes and for safety release in case of emergency. It also has an overflow weir at the top to protect the system from backing up when the storage volume is exceeded, if the system is designed for on-line storage (Figure 3).

Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbon material. A submerged weir (designed to minimize the energy of incoming stormwater) conveys the effluent to the second chamber. The effluent enters the filter layer by overflowing the weir typically 3 ft above the bottom of the structure. The water is filtered through various filtering layers to remove suspended pollutant particles. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber. The third chamber also receives any overflow from the second chamber for an on-line system and overflow from the first chamber flow splitter for an off-line system.

## Applicability

The SFWQ structure is specifically designed for highly urbanized areas where open space is not available. The

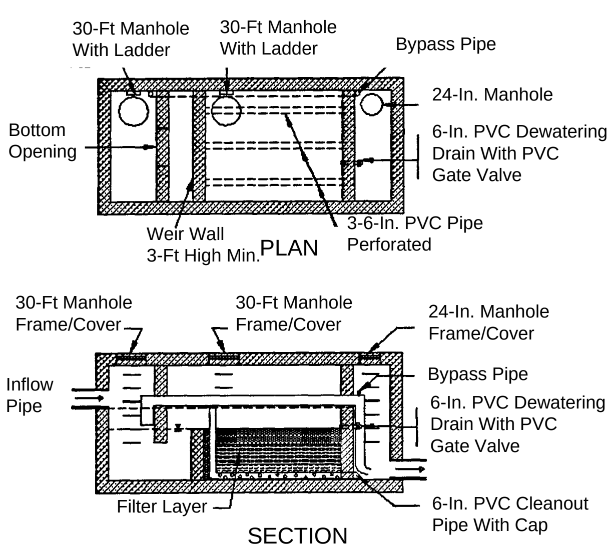


**Figure 2. DC off-line underground sand filter (source: District of Columbia).**

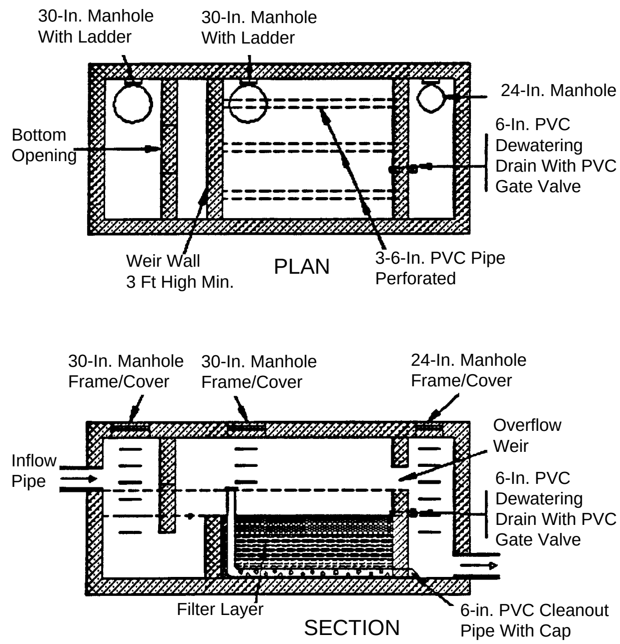


**Figure 3. DC on-line underground sand filter (source: District of Columbia).**

structure works best for impervious catchment areas of 1 acre or less. Multiple systems are recommended for catchment areas greater than 1 acre.

Over 70 underground and surface sand filter structures have been installed in Washington, DC, since 1988. In fact, the structure has been adopted and incorporated in the stormwater management programs of several states and neighboring jurisdictions.

The structure may also be designed to provide detention, especially for on-line application when discharge rates must be modified in accordance with local and municipal regulations. Recommended areas where this device may be used include:

- Surface parking lots.
- Underground parking lots or multilevel garages.
- Parking apron, taxiway, and runway shoulders at airports.
- Emergency stopping and parking lanes and sidewalks.
- Vehicle maintenance areas.
- On-street parking aprons in residential areas.
- Recreational vehicle camping area parking pads.
- Private roads, easement service roads, and fire lanes.
- Industrial storage yards and loading zones.
- Driveways for residential and light commercial use.
- Office complexes.

## Planning Considerations

### *Location*

The SFWQ structure must be located in areas where it is accessible for inspection and maintenance, as well as to the vacuum trucks that are usually required to provide maintenance.

### *Ground Water and Bedrock*

The seasonally high ground-water table and bedrock should be at least 2 to 4 ft below the footing of the structure.

### *Size*

The SFWQ structure may vary in size from a small-site single installation to large or multiple facility installations. Site topography and the presence of underground utilities, however, may limit the size and depth of the system. Use of other practices in combination with the SFWQ structure may solve this problem.

### *Hydraulic Head*

Because the SFWQ structure is a gravity flow system, sufficient vertical clearance between the inverts of the inflow and outflow pipes must be provided. When elevation is insufficient, a well pump may be used to discharge the effluent from the third chamber into the receiving drainage system.

### *Water Trap*

In combined sewer areas, a water trap must be provided in the third chamber to prevent the backflow of odorous gas.

## Design Criteria

In designing the SFWQ structure, the nature of the area, such as imperviousness, determines the control volume of the sand filter chamber. Other recommended steps to consider when designing a SFWQ structure are the following:

- Examine the site topographical conditions and select possible outfalls from the existing drainage or sewer map.
- Review the final grading plans and determine the maximum head available between the proposed inflow and outflow pipes.
- Determine the total connected impervious area.
- Select the design (first flush) runoff based on land use characteristics. (Washington, DC, uses 0.5 in. for surface parking lots, 0.3 in. for rooftops, and 0.4 in. for other impervious surfaces.)
- Estimate the storage volume and the release rate. The storage volume and release rate depends on local stormwater management regulations.
- Select design storm(s). This should be based on the storm frequencies selected by the stormwater management authorities.
- Determine the size of the inflow, outflow, and emergency release pipes. These should be sized to pass the lowest selected storm frequency permitted by local stormwater regulations. (Washington, DC, uses 15-yr, 5-min storms for postdevelopment runoff.)
- Determine detention time. All SFWQ structures should be designed to drain the design (first flush) runoff from the filter chamber 5 to 24 hr after each rainfall event.
- Determine structural requirements. A licensed structural engineer should design the structure in accordance with local building codes.
- Provide sufficient headroom for maintenance. A minimum head space of 5 ft above the filter is recommended for maintenance of the structure. If 5 ft of headroom is not available, a removable top should be installed.

## Design Procedures

### *Determine Design Invert Elevations*

Determine the final surface elevation, invert in, invert out, and bottom invert elevation of the structure (see Figure 4):

$$D_t = (\text{Inv. in} - \text{Inv. out}) + H_w + 1, \quad \text{(Eq. 1)}$$

where

$D_t$ = total depth of structure (ft)
Inv. in = final invert elevation of inflow pipe (ft)
Inv. out = final invert elevation of outflow pipe (ft)
$H_w$ = vertical height of overflow weir (ft)
1 = freeboard constant (ft)

### *Peak Discharge Calculation for Bypass Flow*

Using the Rational Method:

$$Q_{pk} = CIA, \quad \text{(Eq. 2)}$$

where

$Q_{pk}$ = bypass peak flow ($ft_3$/sec)
C = runoff coefficiency (dimensionless)
I = rainfall intensity (in./hr)
A = drainage area (ac)

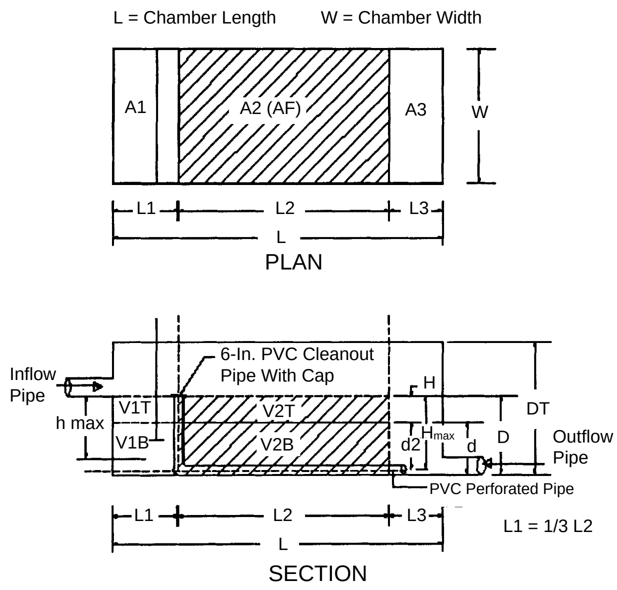


Figure 4. **Design guide for DC sandfilter (source: District of Columbia).**

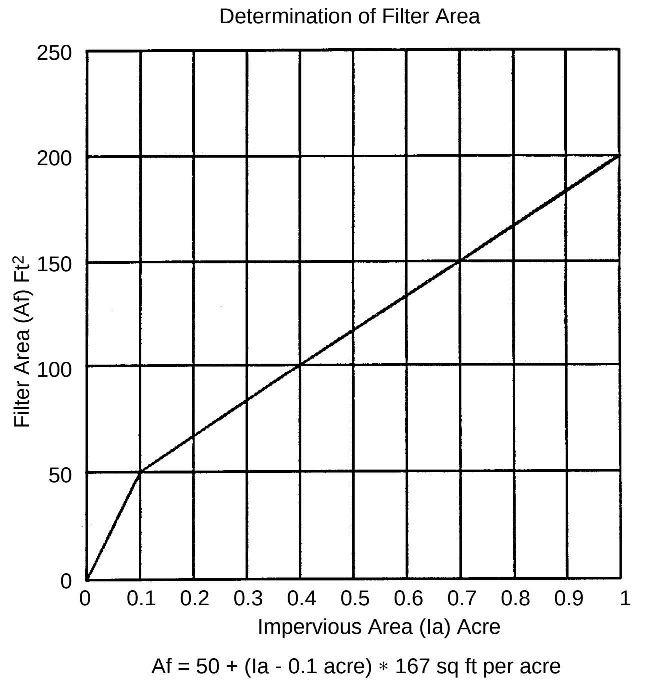


Figure 5. **Filter area versus watershed imperviousness (source: District of Columbia).**

### *Determine Area of Sand Filter*

Use Figure 5 or the following equation:

$A_f = 50 + [Ia - 0.1 \text{ acres}] \times 167 \text{ ft}^3/\text{ac},$ (Eq.3)

where

$A_f$ = sand filter area (ft2)
$I_a$ = impervious area (ac)

### *Determine Storage Volume*

Use the equation

$V_w = (Q_i \times I_a) - (F \times T \times A_f),$ (Eq. 4)

where

$V_w$ = volume storage needed (ft3)
$Q_i$ = first flush runoff (in)
$I_a$ = impervious area ($ft^2$)
F = final infiltration rate for filter (ft/hr)
T = filling time (1 hr, based on empirical data)
$A_f$ = sand filter area ($ft^2$)

### *Calculate Bottom Storage Volume in Second Chamber*

Use the equation

$V_{2b} = Af \times d \times V_v,$ (Eq. 5)

where

$V_{2b}$ = bottom volume of filter chamber (ft3)
$A_f$ = surface area of filter layer (ft2)
d = depth of filter layer (ft)
$V_v$ = sum of void ratio for filter media

### *Calculate Bottom Storage Volume in First Chamber*

Use the equation

$V_{1b} = A_1 \times d,$ (Eq. 6)

where

$V_{1b}$ = bottom volume of first chamber ($ft^3$)
$A_1$ = surface area of first chamber (ft2)
d = depth of filter layer (ft)

Note: $A_f/3 < A1 < A_f/2$ for optimum design condition.

### *Calculate Storage Volume in First and Second Chambers*

Use the equation

$(V_{1t} + V_{2t}) = V_w - (V_{2b} + V_{1b}),$ (Eq. 7)

where

$V_{1t} + V_{2t}$ = sum of top volume of first and second chambers

$V_w$ = volume of water from Equation 4
$V_{2b} + V_{1b}$ = sum of bottom volume of first and second chambers

### *Determine Maximum Storage Depth for On-Line System*

Use the equation

$$D = [(V_{1t} + V_{2t})/(A_1 + A_2)] + d, \quad \text{(Eq. 8)}$$

where

$D$ = maximum storage depth (ft)
$V_{1t} + V_{2t}$ = sum of top volume of first and second chambers
$A_1 + A_2$ = sum of surface area of first and second chambers
$d$ = depth of filter layer (ft)

Note: D must be equal to or smaller than the difference between the invert in and invert out from Equation 1.

### *Determine Size of Submerged and Overflow Weirs*

Submerged weir opening in first chamber:

$$A(h \times l) = Q_{pk}/C \times (2 \times g \times h_{max})^{0.5}, \quad \text{(Eq. 9)}$$

where

$A(h \times l)$ = area of weir opening ($ft^2$)
$Q_{pk}$ = bypass flow from Equation 2 (ft3/sec)
$C$ = 0.6, weir coefficient
$g$ = 32.2 $ft^2/sec$
$h_{max}$ = hydraulic head above the center line of weir (ft)
$h$ = weir height, minimum 1 ft

Overflow weir opening in second chamber:

$$H^{1.5} = Q_{pk}/CL, \quad \text{(Eq. 9a)}$$

where

$H$ = height of weir opening (ft)
$Q_{pk}$ = bypass flow ($ft^3/sec$)
$C$ = 3.33, weir coefficient
$L$ = length of weir opening (ft)

### *Determine Flow Through Filter and Detention Time After Storage Volume Fills Up*

Average flow through the filter:

$$q_f = k \times A_f \times i, \quad \text{(Eq. 10)}$$

where

$q_f$ = flow through the filter ($ft^3/hr$)
$k$ = sand permeability (ft/hr)
$A_f$ = filter area
$i$ = hydraulic gradient ($H_{max}$/2 x filter depth)

Estimate the detention time:

$$T_s = V_w/q, \quad \text{(Eq. 11)}$$

where

$T_s$ = average dewatering time for SFWQ structures (hr)
$V_w$ = volume of first flush storage from Equation 3 ($ft^3$)
$q$ = average flow from Equation 10 ($ft^3/hr$)

### *Develop Inflow and Outflow Hydrographs*

Figure 6 is a typical illustration of inflow/outflow hydrographs for the SFWQ structure.

For inflow hydrograph, use Modified Rational Method Hydrograph with:

$T = T_c$
$T_R = 1.67\ T_c$,

where

$T$ = time to peak
$T_c$ = time of concentration
$T_R$ = recession period

For outflow hydrographs, use the following equations to determine when flow occurs:

when

$$T_c \times Q_{pk} < 2V_w, + \quad \text{(Eq. 12)}$$
$$T = [2*T_c2 - (2T_c2 - 2V_w*T_c/Q_{pk})^{0.5}].$$

when

$$T_c \times Q_{pk} = 2V_w, + \quad \text{(Eq. 13)}$$
$$T = (0.5T_c) + (V_w/Q_{pk})$$

when

$$T_c \times Q_{pk} > 2V_w, + \quad \text{(Eq. 14)}$$
$$T = [(2V_w*T_c)/Q_{pk}]^{0.5}.$$

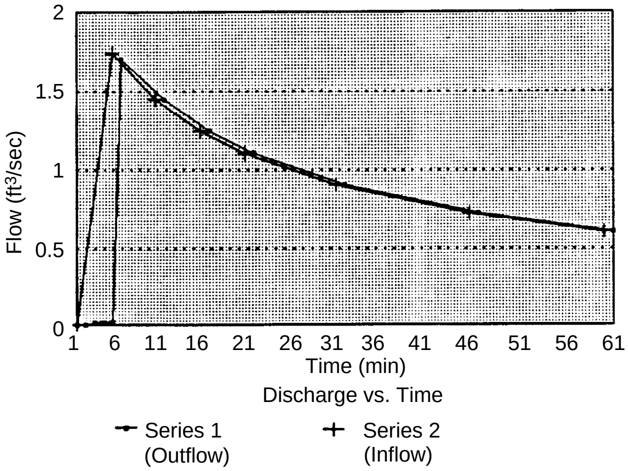


**Figure 6. Typical inflow-outflow hydrograph (source: District of Columbia).**

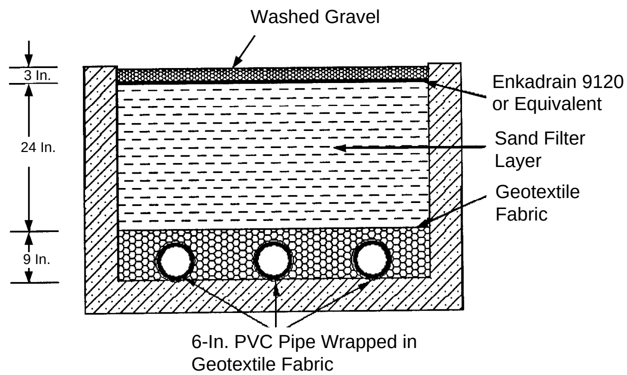


**Figure 7. Cross section of filter compartment (source: District of Columbia).**

## *Filter Layer Details*

Figure 7 is a typical cross section of the filter chamber.

### Upper Gravel Layer

The washed gravel or aggregate layer at the top of the filter may be 1 to 3 in. thick and meet American Society for Testing Materials (ASTM) standard specifications for 1-in. maximum diameter or DC #57 gravel.

### Geotextile Fabrics

The filter fabric (geotextile fabric) beneath the top gravel layer should be Enkadrain 9120 or equivalent with the specifications shown in Table 1.

The filter cloth beneath the sand should meet the specifications shown in Table 2.

The fabric roll should be cut with sufficient dimensions to cover the entire wetted perimeter of the filter area with a 6-in. minimum overlap.Sand Filter Layer

### Sand Filter Layer

The sand filter layer should be 18 to 24 in. deep. ASTM C33 Concrete Sand is recommended, but sand with similar specifications may be used.

**Table 1. Geotextile Fabric Specifications**

| Property | Test Method | Unit | Specification |
|---|---|---|---|
| Material | Nonwoven geotextile fabric | | |
| Unit weight | ASTM D-1777 | oz/yd$^2$ | 4.3 (min) |
| Flow rate | "Falling head test" ASTMD-751 | gpm/ft$^2$ lb | 120 (min) 60 (min) |
| Puncture thickness | | in. | 0.8 (min) |

### Bottom Gravel Layer

The bottom gravel layer surrounding the collector (perforated) pipes should be 1/2- to 2-in. diameter gravel and provide at least 3 in. of cover over the tops of the drainage pipes. No gravel is required under the pipes. The gravel and the sand layer above must be separated by a layer of geotextile fabric that meets the specifications listed above.

### Underdrain Piping

The underdrain piping consists of three 6-in. pipes with 3/8-in. perforations and should be reinforced to withstand the load of the overburden. All piping should be to schedule 40 polyvinyl chloride (PVC) or greater strength.

The minimum grade of piping shall be 1/8 in./ft or 1 percent slope. Access for cleaning all underdrain piping is needed. Cleanouts for each pipe should extend to the invert of overflow weir or maximum surface elevation of the storage water.

Each pipe should be carefully wrapped with geotextile fabric that meets the above specifications before placement in the filter.

**Table 2. Filter Cloth Specifications**

| Property | Test Method | Unit | Specification |
|---|---|---|---|
| Material | Nonwoven geotextile fabric | | |
| Unit weight | | oz/yd$^2$ | 8.00 (min) |
| Filtration rate | | in./sec | 0.08 (min) |
| Puncture strength | ASTM D-751 (Modified) | lb | 125 (min) |
| Mullen burst strength | ASTM D-751 | psi | 400 (min) |
| Tensile strength | ASTM D-1682 | lb | 300 (min) |
| Equivalent opening size | U.S. Standard Sieve | no. | 80 (min) |

## Construction Specifications

The SFWQ structure may be either cast-in-place or precast. In Washington, DC, precast structures require advanced approval. The approved erosion and sediment control plans should include the specific measures to provide the protection of the filter system before the final stabilization of the site.

### *Excavation and Installation*

Excavation for SFWQ structure and connecting pipes should include removal of all materials and objects encountered in excavation; disposal of excavated material as specified in the approved erosion and sediment control plans; maintenance and subsequent removal of any sheeting, shoring and bracing; dewatering and precautions; and work necessary to prevent damage to adjacent properties resulting from this excavation. Access manholes and steps to the filtration system should conform to local standards.

### *Leak Test*

After completion of the SFWQ structure shell, a leak test may be performed to verify watertightness before the filter layers are installed.

### *Filter Materials*

All filter materials in the second chamber should be placed according to construction and materials standards and specifications, as specified on an approved construction plan.

### *Completion and Site Stabilization*

No runoff should be allowed to enter the sand filter system before completion of all construction activities, including revegetation and final site stabilization. Construction runoff should be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new, clean filter materials before a regulatory inspector approves its completion.

### *System Calibration and Verification*

The water level in the filter chamber should be monitored by the design engineer after the first storm event before the project is certified as completed. If the dewatering time of the filter chamber takes longer than 24 hr, the top gravel layer and filter fabric underneath must be replaced with a more rapid draining fabric and clean gravel. The structure should then be checked again to ensure a detention time that is less than 24 hr.

## Maintenance Requirements

The SFWQ structure is designed to minimize maintenance. It is subject to clogging, however, by sediment, oil, grease, grit, and other debris. Actual performance and service life of the structure is not available at this time. Nevertheless, it is still very important to provide general standard maintenance guidelines to maintain adequate structure operation. The maintenance of the system includes the following steps:

- The water level in the filter chamber should be monitored by the owner on a quarterly basis and after every large storm for the first year after completion of construction. A log of the results should be maintained, indicating the rate of dewatering after each storm and the water depth for each observation. Once the regulatory stormwater inspector indicates that satisfactory performance of the structure has been demonstrated, the monitoring schedule may be reduced to an annual basis.
- As with other pretreatment structures, the first chamber must be pumped out semiannually. If the chamber contains an oil skim, it should be removed by a firm specializing in oil recovery and recycling. The remaining material may then be removed by a vacuum pump truck and disposed of in an approved landfill. After each cleaning, refill the first chamber to a depth of 3 ft with clean water to reestablish the water seal.
- After approximately 3 to 5 yr, the upper layer of the filter can be expected to become clogged with fine silt. When the drawdown time for the filter exceeds 72 hr, the upper layer of gravel and geotextile fabric must be removed and replaced with new, clean materials conforming to the original specifications.

## Conclusion and Discussion

At the present time, the environmental and economic impacts of the SFWQ structure have not been fully evaluated. A long-term monitoring program is being implemented in Washington, DC, to determine water quality benefits and address long-term maintenance concerns. The results from this monitoring effort will provide important information on the removal efficiency of common urban pollutants. In addition, the monitoring data will provide information on actual headloss in the system, which will indicate the need for filter replacement.

Based on the results of the Austin, Texas, monitoring program on its sand filter systems and on several years of success in the application of the SFWQ structure in Washington, DC, the feasibility of the SFWQ structure has been demonstrated for use in an urban environment. The authors believe that the SFWQ structure may be used as an alternative urban BMP for highly developed areas where other options are not available.

In conclusion, the design presented here is an attempt to provide an alternative solution to control nonpoint source pollution from urban stormwater runoff. The application of this system should be viewed with some caution, as the structure has not been monitored for optimal effectiveness.

When the SFWQ structure is used strictly as a gravity flow system, one of its limitations is that it requires a hydraulic head of at least 4 ft relative to the outflow pipe. To minimize this problem, further study is needed to evaluate the different thicknesses of the sand layers (with thicknesses such as 18, 12, and 6 in.) to determine the relationship between the depth of sand layer and pollutant removal efficiency.

## Acknowledgments

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# *Stormwater Measures for Bridges: Coastal Nonpoint Source Management in South Carolina*

**H. Stephen Snyder**
**South Carolina Coastal Council,**
**Charleston, South Carolina**

## Abstract

Although stormwater runoff from bridges has a direct pathway to estuaries, rivers, and lakes, little research has been undertaken to directly measure the concentration of pollutants flushed from the bridge surface or the impact of those pollutants on the receiving water body. A general correlation can be made, however, from the body of research available concerning runoff from roads and streets in general and from the wider body of information regarding urban runoff characteristics. The general assumption is that runoff from highways (and bridges) can negatively affect the water quality of receiving waters through the shock of acute loadings during rainfall events and through long-term exposure and/or accumulations of pollutants in sediments or marine organisms. Research does indicate a relationship between the average daily traffic volume and potential water quality impacts. Concern is heightened where the runoff has a direct, unobstructed pathway to the receiving waters and, even more so, where the receiving waters are extremely sensitive, such as shellfish habitat.

This paper provides a brief overview of potential water quality pollutants from highway and bridge runoff, then focuses on management and control measures for runoff from bridges. These include requirements of Section 6217 of the Coastal Zone Act Reauthorization Amendments and stormwater management requirements for bridges in the coastal zone of South Carolina. Included is a case study of retrofitting a major bridge already designed and under construction, which transverses significant shellfish resources in coastal South Carolina.

## Introduction

South Carolina's 187-mile coastline is only the facade for some 3,000 shoreline miles of estuaries, bays, rivers, and creeks that intertwine among some 500,000 acres of coastal marshes and wetlands. This immense coastal system supports approximately 279,000 acres of estuarine shellfish-growing waters and thousands of acres of other sensitive habitats. For people to live and work in this environment, all of these coastal resources, rivers, bays, marshes, and sensitive habitats must be transversed in one form or another, most often by roadways and bridges. These roadways and bridges and their associated uses can provide a direct source of contaminants to our coastal waters and, as such, must be managed to reduce or alleviate the potential impacts.

For coastal states, addressing pollution from bridges may no longer be a choice. Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 requires states with coastal zone programs to develop coastal nonpoint source pollution programs. Such programs must address pollution in the following areas: agriculture, silviculture, hydrologic modifications, marinas, and urban settings, the latter of which include roads and, even more specifically, bridges.

A basic assumption contained herein is that the results of studies on highways and their associated pollution potential from runoff are also applicable to highway bridges.

## Contaminants

A series of studies sponsored by the U.S. Department of Transportation in the 1980s (1-3) confirms the presence and possible sources of a wide variety of contaminants that may be associated with roadways and bridges. A basic listing is presented in Table 1. These contaminants accumulate on roadway surfaces between major removal events, such as rainfalls and street sweeping (which may be rare or nonexistent in nonurban areas). The severity and order of magnitude of these contaminants are site specific and variable, and can depend on such factors as traffic characteristics, highway or bridge design, maintenance activities, accidental spills, surrounding land use, and climate.

**Table 1. Common Highway Runoff Constituents and Their Primary Sources (1)**

| Constituent | Primary Sources |
|---|---|
| Particulates | Pavement wear, vehicles, atmosphere, highway maintenance |
| Nitrogen, phosphorus | Atmosphere, roadside fertilizer application |
| Lead | Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear |
| Zinc | Tire wear (filler material), motor oil (stabilizing additive), grease |
| Iron | Auto body rust, steel highway structures (guardrails, bridges, etc.), moving engine parts |
| Copper | Metal plating, bearing and bushing wear; moving engine parts; brake lining wear; fungicides and insecticides (roadside maintenance operations) |
| Cadmium | Tire wear (filler material), insecticides |
| Chromium | Metal plating, moving engine parts, brake lining wear |
| Nickel | Diesel fuel gasoline (exhaust) and lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving |
| Manganese | Moving engine parts |
| Bromide | Auto exhaust |
| Cyanide | Anticake compound (ferric ferrocyanide, etc.) used to keep deicing salt granular |
| Chloride | Deicing salts |
| Sulphate | Roadway beds, fuel, deicing salts |
| Petroleum | Spills, leaks, or blow-by of motor lubricants; antifreeze, and hydraulic fluids, asphalt surface leachate |
| Polychlorinated biphenyls (PCBs), synthetic pesticides | Spraying of highway right-of-ways, background atmospheric deposition, PCB catalyst in tires |
| Pathogenic bacteria (indicators) | Soil, litter, bird droppings, trucks hauling livestock and stockyard waste |
| Rubber | Tire wear |
| Asbestos | Clutch and brake lining wear |

The studies have revealed some interesting results that may influence management decisions. To elaborate on one pollutant, tests (1) indicated that the pathogenic bacteria indicators fecal coliform and fecal *Streptococcus* were not consistently present on roadway systems at any given time or place; their presence is most often associated with nonspecific events, i.e., animal and bird droppings, soil spills, and road kills. When present, however, the bacteria can remain viable for relatively long periods in highway sweepings (up to 7 weeks) and up to 13 days in stagnant storm sewer systems. As one would expect, the tests showed that the coliform bacteria were consistently lower when runoff was conveyed through a grassy area, although none of the standard nonpoint source management measures effectively kills coliforms and their associated microbes (2).

According to the U.S. Department of Transportation (1), the major portion of priority pollution load in highway runoff was attributed to metals (e.g., lead, zinc, and copper), although a significant number of organic pollutants were present in the highway environment.

Studies (4, 5) indicate that the magnitude of pollutants associated with highway runoff is related to traffic volume. Research (2) tends to indicate that 30,000 average daily traffic (ADT) is a general threshold for the potential of impacts from highway runoff; however, several variables must be factored into this conclusion, including sensitivity of receiving waters, distance to receiving waters, type of traffic, road or bridge design, and others.

The U.S. Department of Transportation (2) has drawn the following conclusions from these studies and other literature concerning highway runoff pollution potential:

- Highway runoff does have the potential to adversely affect the water quality and aquatic biota of receiving waters.
- The significance of these adverse effects is variable by highway type and design, receiving water, and runoff event.
- Runoff from urban highways with high ADT volumes may have a relatively high potential to cause adverse effects.
- Runoff from rural highways with low ADT volumes has a relatively low potential to cause adverse effects.

## Basic Management Practices and Processes

Of the variety of best management practices available for nonpoint source pollution control, four basic management measures are generally considered cost effective for treatment of highway runoff based on effectiveness for specific pollutants, relative capital costs, land requirements, and operation and maintenance costs (2):

- Vegetative controls
- Wet detention basins
- Infiltration basins
- Wetlands

Pollution measures that were not considered effective when used as a sole management tool were street cleaning, catch basins, filtration devices for sediment control, dry detention ponds, and porous pavements (2). The first three methods were not effective in capturing the fine sediments to which many pollutants attach themselves, while the dry detention pond tended to reflush the settled particles after each rainfall event. Porous pavement is limited to low-volume traffic areas, such as parking lots, because of current highway construction standards.

All of the measures have in common several physical or biochemical processes that occur to provide the necessary control of pollutants: settling, filtering, adsorption, bioassimilation, biodegradation, and volatilization or evaporation. Table 2 lists the process associated with each management measure as related to the general type of pollutant control.

## Management Measures for Bridges

Although bridges can be assumed to cause the same types of water quality impacts as highways, and although the techniques to manage those impacts are fairly straightforward and generally well accepted, the unique location of bridges presents some problems. First, the runoff from the bridge must be intercepted from seeking its natural pathway and routed back to high land or another area suitable for treatment; secondly, land areas for treatment are usually limited.

Collection and transportation are most easily solved in the design of the bridge, although in coastal areas runoff may have to be transported long distances with little grade. The physical land requirements for the appropriate treatment method, however, tend to be the most limiting factors. Solutions are very site specific and must be included in the earliest planning stages of the bridge. Topography at the bridge/land junction is often the single most important factor in considering the design of an appropriate treatment method, although other factors, such as high water tables, soil types, and adjacent land use, also can be important in the design consideration process. The design of the stormwater system should not drive the design of the bridge, but neither should the design of the bridge preclude the design of an effective stormwater treatment system.

All of the traditional stormwater management methods can be considered for treatment of runoff from bridges: wet detention ponds, infiltration systems, grassed waterways, and wetlands. These can be used even in combination with less favorable methods, such as frequent sweeping or catch basins, if the lack of good alternatives so dictates. Other opportunities that may be present in the area should also be considered, such as nearby spoil disposal containment areas, preexisting treatment systems for nearby development, or discharge routing to less sensitive areas.

The U.S. Environmental Protection Agency (EPA) (6) lists several general guidelines and management practices for illustrative purposes, specifically for bridges, in the Section 6217 management measure guidance document:

**Table 2. Principal Pollutant Fate Processes by Major Management Measures**

| | Management Measures | | | |
|---|---|---|---|---|
| **Pollutant** | **Vegetative Control** | **Detention Basins** | **Infiltration Systems** | **Wetlands** |
| Heavy metals | Filtering | Adsorption, settling | Adsorption, filtration | Adsorption, settling |
| Toxic organics | Adsorption | Adsorption, settling, volatilization | Adsorption, biodegradation | Adsorption, settling, biodegradation, volatilization |
| Nutrients | Bioassimilation | Bioassimilation | Absorption | Bioassimilation |
| Solids | Filtering | Settling | Adsorption, settling | Adsorption |
| Oil and grease | Adsorption | Adsorption, settling | Adsorption | Adsorption, settling |
| Biochemical oxygen demand | Biodegradation | Biodegradation | Biodegradation | Biodegradation |
| Pathogens | NA | Settling | Filtration | NA |

NA = information not available

- Coordinate design with the Federal Highway Administration (FHWA), U.S. Coast Guard, U.S. Army Corps of Engineers, and other state and federal agencies as appropriate.
- Review National Environmental Policy Act requirements to ensure that environmental concerns are met.
- Avoid highway locations requiring numerous river crossings.
- Direct pollutant loadings away from bridge decks by diverting runoff waters to land for treatment.
- Restrict the use of scupper drains on bridges less than 400 ft in length and on bridges crossing very sensitive ecosystems.
- Site and design new bridges to avoid sensitive ecosystems.
- On bridges with scupper drains, provide equivalent urban runoff treatment in terms of pollutant load reduction elsewhere on the project to compensate for the loading discharged off the bridge.

Regardless of the "illustrative" nature of the above practices, EPA and the National Oceanic and Atmospheric Administration (NOAA) expect the states to address nonpoint pollution from bridges and to adopt enforceable policies by 1995 to manage the runoff or to document why such runoff is not a problem.

## South Carolina's Approach

In 1988, the South Carolina Coastal Council was faced with the permitting of a new 2-mile bridge connecting the mainland with a major developed barrier island (see below) and crossing a major shellfish-producing area. As an outcome of the permitting of this project, the Coastal Council developed a set of guidelines to use in conjunction with the South Carolina Department of Highways and Public Transportation to allow all parties to anticipate the design of stormwater controls in new bridges. It is not unusual for bridges to be designed well in advance of the permitting process, and the inclusion of new design criteria can cause both new expenses and a politically unpleasant situation. The guidelines have been in use since 1989 and have been introduced as regulations to the 1993 South Carolina General Assembly. The regulations appear to meet the basic intent of the EPA/NOAA Section 6217 guidance, although this has yet to be determined. The basic regulations are as follows.

### *Stormwater Management Requirements for Bridge Runoff*

The following are the criteria used to address stormwater management for bridges traversing saltwater and critical areas.

- No treatment is necessary for runoff from bridge surfaces spanning Class SA and Class SB tidal saltwaters. (SA and SB waters are suitable for primary and secondary contact recreation, crabbing, and fishing. The two classes differ in their dissolved oxygen [DO] limitations: SA waters must maintain daily averages of not less than 5.0 mg/L, and SB waters must maintain DO levels not less than 4.0 mg/L.) This runoff can be discharged through scupper drains directly into surface waters. The use of scupper drains, however, should be limited as much as possible.
- If the receiving water is classified as either outstanding resource waters (ORW) or shellfish harvesting waters (SFH), then the stormwater management requirements shall be based on projected traffic volumes and the presence of any nearby shellfish beds. Table 3 lists the necessary treatment practices over the different classes of receiving waters.
- The ADT volume is based on the design carrying capacity of the bridge.

**Table 3. Requirements for Stormwater Management on Bridges in the Coastal Zone, South Carolina**

| | ADT Volume | |
|---|---|---|
| **Water Quality Classification** | **0-30,000** | **30,000** |
| ORW (within 1,000 ft of shellfish beds) | A | A |
| ORW (not within 1,000 ft of shellfish beds) | B | B |
| SFH (within 1,000 ft of shellfish beds) | B | A |
| SFH (not within 1,000 ft of shellfish beds) | B | B |
| SFH (not within 1,000 ft of shellfish beds) | B | B |
| SA (exceptional) | C | C |
| SB (high quality) | C | C |

A = The first 1-in. of runoff from the bridge surface must be collected and routed to an appropriate stormwater management system or routed so that maximum overland flow occurs, encouraging exfiltration before reaching the receiving water body. Periodic vacuuming of the bridge surface should be considered.

B = A stormwater management plan must be implemented that may require the overtreatment of runoff from associated roadways to compensate for the lack of direct treatment of runoff from the bridge surface itself. Periodic vacuuming should be considered. The use of scupper drains should be limited as much as possible.

## The Isle of Palms Connector: A Case Study in Retrofitting

The incorporation of a stormwater management system into a bridge design usually can be done without any great difficulty. Trying to incorporate a system into a bridge already designed and ready for permitting, however, can be much more difficult. Such was the case with the Isle of Palms Connector, an 11,500-ft, $30 million bridge that was to provide alternate access to the Isle of Palms, a barrier island town just outside of Charleston, South Carolina. The bridge route called for the crossing of some 9,000 ft of marsh, two major marsh creeks, and the Intracoastal Waterway. Location and environmental studies and basic bridge design were completed in 1979, the same year the state's coastal zone management program was authorized. Funding limitations slowed the process until 1987, when federal funds became available.

The proposed route for the Isle of Palms Connector crossed over some of the state's most productive commercial and recreational shellfish grounds. The live oyster volume in Hamlin Creek and Swinton Creek alone was surveyed by the South Carolina Wildlife and Marine Resources Department at 32,000 bushels. Annual clam production potential in the immediate area of the bridge is estimated to be between 140,000 and 250,000 clams.

The bridge was originally designed with traditional methods of handling stormwater; water was drained directly from the bridge through scuppers except at one previously identified sensitive area, where discharge was eliminated. Because there were no objections to the stormwater design in the original environmental impact assessment, approved by the FHWA in 1986, the South Carolina Department of Highways and Public Transportation was reluctant to make any changes. Relocation of the bridge was not an option, nor, as it turned out, was redesign of the bridge. The bridge was designed with approximately 9,000 ft at 0.0 percent grade, with elevated spans over the Intracoastal Waterway and one of the creeks (Figure 1). The State Highway Department estimated redesign to accommodate positive flows to both ends of the bridge at $10 million, a one-third increase in bridge cost (7).

The South Carolina Coastal Council, however, as primary permitting agency for the bridge, was sensitive to public demand that the bridge must incorporate a stormwater management system that met basic coastal stormwater guidelines (8). After several meetings, which included public input, the South Carolina Department of Highways and Transportation agreed to work with the Coastal Council in addressing stormwater within the limits of two constraints: the bridge location could not be changed, and the stormwater system must be adaptable to the existing bridge design. Once this decision was reached, both agencies began a serious and cooperative effort in resolving the problem. It was immediately apparent that the traditional methods of stormwater treatment usually employed on high land must be ruled out; other than pumping, which was explored and rejected due to cost, there was no way to get the runoff back to high ground for treatment. Therefore, the study team threw

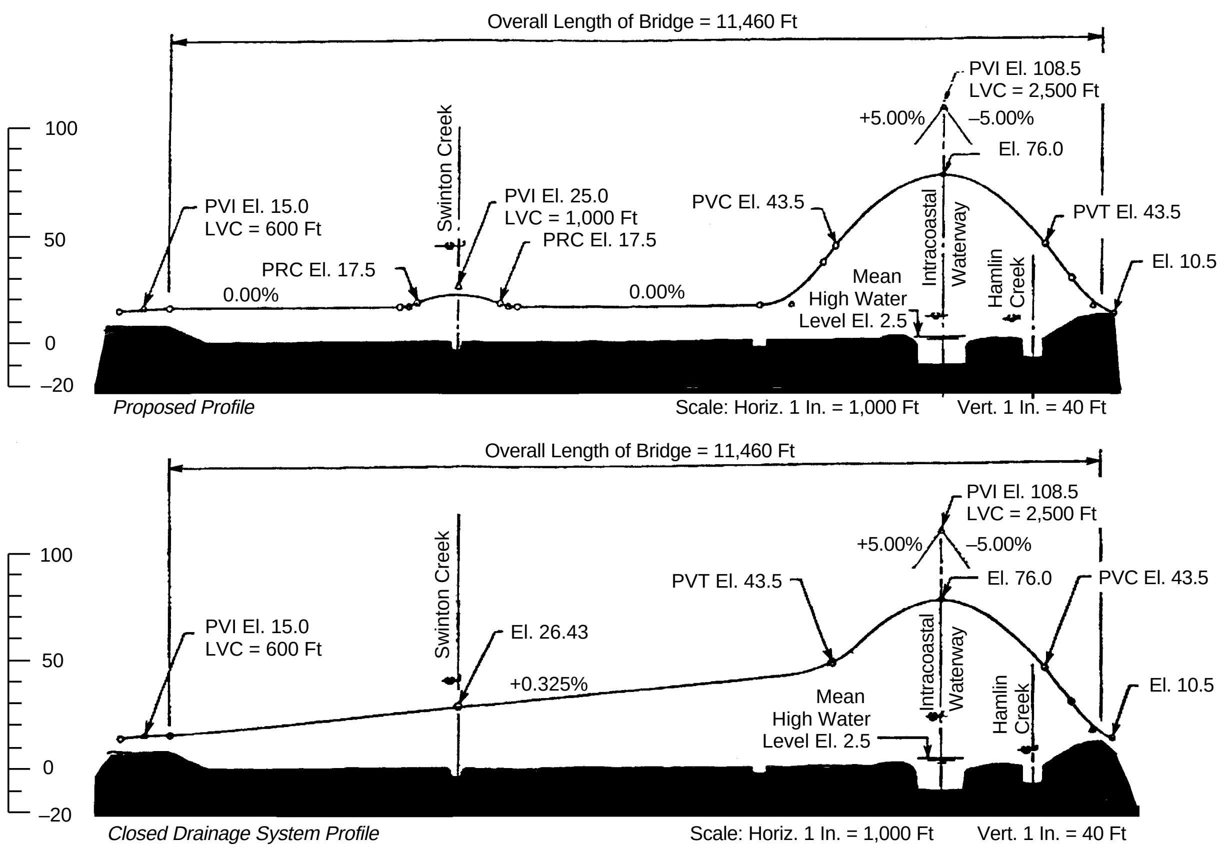


**Figure 1. Proposed and closed drainage system profiles for Isle of Palms Connector.**

out the preconceived traditional approaches and focused on the basic tenents of stormwater management: retention, settling, and pollutant removal. A variety of alternatives were identified, evaluated, and rejected for various reasons. Among these alternatives were storage and retention in gutters of several configurations along the shoulder of the bridge roadway and the design of an “in the marsh” sand filtering system constructed in large cylinders.

What emerged from this process was the design of an open-faced “runoff pan,” 15 ft long by 32 in. wide, to be bolted in place to catch the discharge from each scupper drain (Figure 2). The pan, constructed of fiberglass, was 1 ft deep with a baffle overflow to prevent the discharge of oil and grease. In addition to containing the first 3/4 in. of runoff, the pans were to be managed with a vigorous maintenance program that would include dry/wet vacuuming on a to-be-determined basis and disposal of the residue in accordance with state hazardous waste regulations. The estimated cost for the stormwater management system, to include piping of runoff from the vertical expansions of the bridge to high ground and an adjacent spoil disposal area, was about 3.5 percent of the total bridge cost.

Accompanying this alternative was the commitment of the State Highway Department and the Coastal Council to develop a monitoring program to test the effectiveness of this technique. The monitoring program was to be implemented on completion of the bridge, estimated for the fall of 1993. Background data was collected in the summer and fall of 1993.

Both agencies, along with the concerned public, eagerly await the results of the monitoring. If successful, the runoff pan may provide one alternative for addressing stormwater management on existing bridges crossing sensitive waters.

## Conclusion

Roadways and bridges are certainly not unique in their potential contribution to lessened water quality. Virtually all human activities on the land, on the water, and in the air contribute to the problem. No one solution to correct the problem exists; rather, the solution lies with the incremental “micromanagement” of each specific activity that contributes to the problem.

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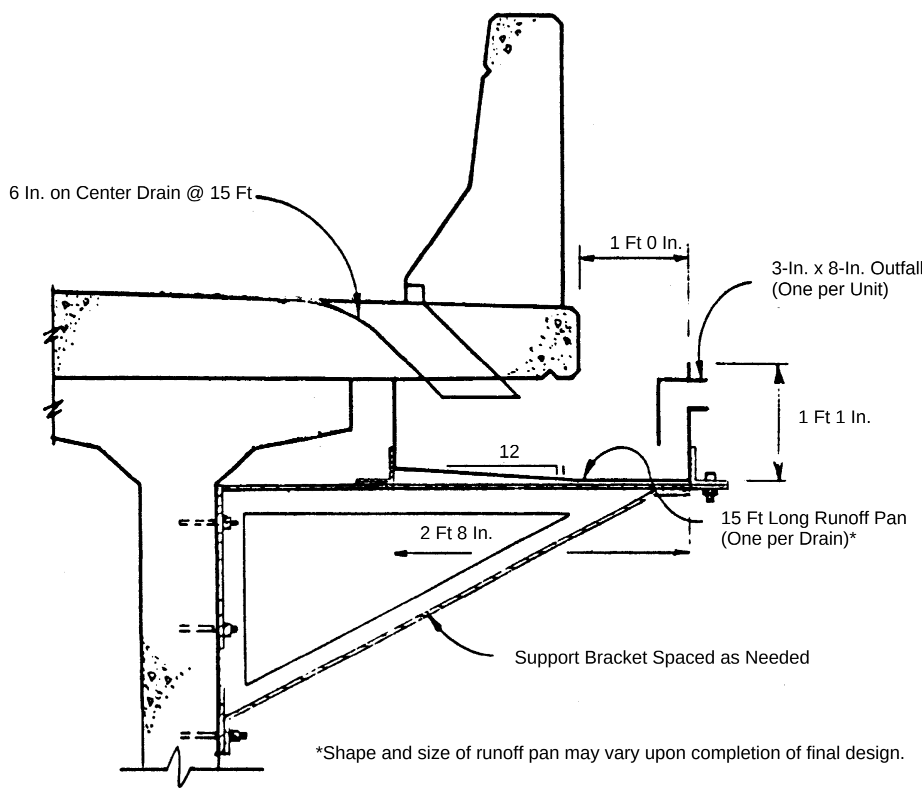


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# *Controlling Pollutants in Runoff From Industrial Facilities*

**Kevin Weiss**
**Storm Water Section, NPDES Permits Division, U.S. Environmental Protection Agency, Washington, DC**

## Abstract

Industrial facilities can be significant contributors of pollutants to urban runoff. On November 16, 1990, the U.S. Environmental Protection Agency (EPA) published National Pollutant Discharge Elimination System (NPDES) permit application requirements for "stormwater discharges associated with industrial activities." These regulations provide a framework for reducing pollutants in runoff from the industrial facilities addressed. EPA subsequently developed a long-term strategy for issuing NPDES permits for these discharges. As the initial step in this strategy, the Agency issued general permits on September 9, 1992, and September 25, 1992, for the majority of stormwater discharges in states where EPA issues NPDES permits. This paper provides an overview of major categories of sources that contribute pollutants to runoff at industrial sites and describes pollution prevention measures in EPA's NPDES general permits.

## Introduction

Pollutants in urban runoff depend in part on the nature of land use. Several studies indicate that runoff from industrial land uses is of relatively poorer water quality than runoff from other general land uses (1-5). In addition, industrial sites can be significant sources of polluted, uncontrolled nonstormwater to separate storm sewers (6, 7).

## Source of Pollutants to Industrial Runoff

The volume and quality of stormwater discharges associated with industrial facilities depend on several factors, including the industrial activities occurring at the facility, the nature of precipitation, and surface imperviousness. The sources of pollutants that can affect the quality of stormwater from industrial facilities differ with the type of operations and specific facility features. For example, air emissions may be a significant source of pollutants at some facilities, material storage operations at others, and still other facilities may discharge stormwater associated with industrial activity with relatively low levels of pollutants.

Six classes of activities can be identified as major potential sources of pollutants in stormwater discharges associated with industrial activity (7-11):

- Loading or unloading of dry bulk materials or liquids.
- Outdoor storage of raw materials or products.
- Outdoor process activities.
- Dust or particulate generating processes.
- Illicit connections or inappropriate management practices.
- Waste disposal practices.

The potential for pollution from many of these activities may be influenced by the presence and use of toxic chemicals.

Loading and unloading operations typically are performed along facility access roads and railways and at loading/unloading docks and terminals. These operations include pumping of liquids or gases from trucks or rail cars to a storage facility or vice versa; pneumatic transfer of dry chemicals to or from the loading or unloading vehicle; transfer by mechanical conveyor systems; and transfer of bags, boxes, drums, or other containers from vehicles by forklift trucks or other materials handling equipment. Material spills or losses may discharge directly to the storm drainage systems or may accumulate in soils or on surfaces, to be washed away during a storm or facility washdown.

Outdoor storage includes the storage of fuels, raw materials, byproducts, deicing chemicals, intermediates, final products, and process residuals and wastes. Methods of material storage include use of storage containers (e.g., drums or tanks), platforms or pads, bins, silos, boxes, and piles. Materials, containers, and material storage areas exposed to rainfall or runoff may contribute pollutants to stormwater when solid materials wash off or materials dissolve into solution.

Other outdoor activities include certain types of manufacturing and commercial operations and land-disturbing operations. Although many manufacturing activities are performed indoors, some activities (e.g., equipment and vehicle maintenance and cleaning, timber processing, rock crushing, vehicle maintenance and cleaning, and concrete mixing) typically occur outdoors. Processing operations may result in liquid spillage and losses of material solids to the drainage system or surrounding surfaces, or creation of dusts or mists that can be deposited locally. Some outdoor industrial activities cause substantial physical disturbance of land surfaces that result in soil erosion by stormwater. For example, disturbed land occurs in construction and mining. Disturbed land may result in soil losses and other pollutant loadings associated with increased runoff rates. Facilities whose major process activities are conducted indoors may still apply chemicals such as herbicides, pesticides, and fertilizer outdoors for a variety of purposes.

Dust or particulate generating processes include industrial activities with stack emissions or process dusts that settle on plant surfaces. Localized atmospheric deposition can be a particular concern with heavy manufacturing industries. For example, monitoring of areas surrounding smelting industries has shown much higher levels of metals at sites nearest the smelter. Other industrial sites, such as mines, cement manufacturing plants, and refractories, generate significant levels of dusts.

Illicit connections or inappropriate management practices result in improper nonstormwater discharges to storm sewer systems. Pollutants from nonstormwater discharges to the storm sewer systems are caused typically by a combination of improper connections, spills, improper dumping, and improperly disposed of rinse waters, cooling waters, or other process and sanitary wastewater. Often dischargers believe that the absence of visible solids in a discharge is equivalent to the absence of pollution. Illicit connections are often associated with floor drains that are connected to separate storm sewers. Rinse waters used to clean or cool objects discharge to floor drains connected to separate storm sewers. Large amounts of rinse waters that discharge to floor drains may originate from industries using regular washdown procedures; for example, bottling plants use rinse waters for removing waste products, debris, and labels. Rinse waters can be used to cool materials by dipping, washing, or spraying objects with cool water; for example, rinse water is sometimes sprayed over the final products of a metal plating facility for cooling purposes. Condensate return lines of heat exchangers often discharge to floor drains. Heat exchangers, particularly those used under stressed conditions (e.g., exposure to corrosive fluids), such as in the metal finishing and electroplating industry, may develop pinhole leaks that result in contamination of condensate by process wastes. These and other nonstormwater discharges to storm sewers may be intentional, based on the belief that the discharge does not contain pollutants, or they may be inadvertent, if the operator is unaware that a floor drain is connected to the storm sewer.

Waste management practices include temporary storage of waste materials and operations at landfills, waste piles, and land application sites that involve land disposal. Outdoor waste treatment operations also include wastewater and solid waste treatment and disposal processes, such as waste pumping, additions of treatment chemicals, mixing, aeration, clarification, and solids dewatering.

## Options for Control

Options for controlling pollutants in stormwater discharges associated with industrial activity are discussed below in terms of two major pollutant sources: 1) materials discharged to separate storm sewers via illicit connections, improper dumping, and spills; and 2) pollutants associated with runoff.

### *Nonstormwater Sources*

As discussed above, nonstormwater discharges to separate storm sewers come from a wide variety of sources, including illicit connections, improper dumping, spills, or leakage from storage tanks and transfer areas. Measures to control spills and visible leakage can be incorporated into the best management practices discussed below.

In many cases, operators of industrial facilities may be unaware of illicit discharges or other nonvisible sources of nonstormwater to a storm sewer. In such cases, the key to controlling these discharges is to identify them. Several methods for identifying the presence of nonstormwater discharges are discussed below. (A more complete discussion of methods to identify illicit connections can be found in U.S. EPA [6, 12]). A comprehensive evaluation of the storm sewers at a facility often should incorporate several of the following methods:

- *Evaluation of drainage map and inspections:* Drainage maps should identify the key features of the drainage system (i.e., each of the inlet and discharge structures, the drainage area of each inlet structure, storage and disposal units, and materials loading areas) that may be the source of an illicit discharge or improper dumping. In addition, floor drains and other water disposal inlets thought to be connected to the sanitary sewer should be identified. A site inspection can be used to augment and verify map development. These inspections, along with the use of the drainage map, can be coordinated with other identification methods discussed below.

- *End-of-pipe screening:* Discharge points or other access points such as manhole covers can be inspected for the presence of dry weather discharges and other signs of nonstormwater discharges. Dry weather flows, material deposits, and stains are often indicators of illicit connections. Dry weather flows can be screened by a variety of methods. Inexpensive onsite tests include measuring pH; observing for oil sheens, scums, and discoloration of pipes and other structures; and colorimetric detection for chlorine, detergents, metals, and other parameters. In some cases, it may be appropriate to collect samples for more expensive analysis in a laboratory for fecal coliform, fecal *Streptococcus,* volatile organic carbon, or other appropriate parameters.

- *Manhole and internal TV inspection:* Inspection of manholes and storm sewers, either physically or by television, can be used to identify a potential entry point for illicit connections. TV inspections are relatively expensive and generally should be used only after a storm sewer has been identified as having illicit connections.

- *Dry weather testing:* Where storm sewers do not normally discharge during dry weather conditions, water can be introduced into floor drains, toilets, and other points where nonstormwater discharges are collected. Storm drain outlets are then observed for possible discharges.

- *Dye testing:* Dry weather discharges from storm sewers can occur for several legitimate reasons, including ground-water infiltration or the presence of a continuous discharge subject to a National Pollutant Discharge Elimination System (NPDES) permit. Where storm sewers do have a discharge during dry weather conditions, dye testing for illicit connections can be used. Dye testing involves introducing fluorometric or other types of dyes into floor drains, toilets, and other points where nonstormwater discharges are collected. Storm drain outlets and manholes are then observed for possible discharges. Dye testing can also be used to identify unknown submerged outfalls to nearby receiving waters.

- *Water balance:* Many sewage treatment plants require that industrial discharges measure the volume of effluent discharged to the sanitary sewer system. Similarly, the volume of water supplied to a facility is generally measured. A significantly higher volume of water supplied to the facility relative to that discharged to the sanitary sewer and other consumptive uses may be an indication of illicit connections. This method is limited by the accuracy of the flow meters used.

- *Schematics:* Where they exist, accurate piping schematics can be inspected as a first step in evaluating the integrity of the separate storm sewer system. The use of schematics is limited because schematics usually reflect the design of the piping system and may not reflect the actual configuration constructed. Schematics should be updated or corrected based on additional information found during inspections.

Smoke tests are sometimes listed in the literature as a method for detecting illicit connections to separate storm sewers. While smoke tests can be used to identify inflow of stormwater to sanitary sewers, they can be much less effective for identifying discharges of nonstormwater to storm drains. This is because many nonstormwater drainage locations have a sewer gas trap that blocks smoke used in a test. Smoke tests can identify nonstormwater discharges to storm drains if the piping for the nonstormwater discharge has a vent or does not have a sewer gas trap.

## Options for Preventing Pollutants in Stormwater

The following five categories describe options for reducing pollutants in stormwater discharges from industrial plants:

- Providing end-of-pipe treatment.
- Implementing best management practices (BMPs) to prevent pollution.
- Diverting stormwater discharge to treatment plants.
- Using traditional stormwater management practices.
- Eliminating pollution sources/water reuse.

A comprehensive stormwater management program for a given plant often includes controls from each of these categories. Development of comprehensive control strategies should be based on a consideration of plant characteristics.

### End-of-Pipe Treatment

At many types of industrial facilities, it may be appropriate to collect and treat the runoff from targeted areas of the facility. This approach was taken with the 10 industrial categories with national effluent guideline limitations for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

### Best Management Practices

BMPs encompass a wide range of management procedures, schedules of activities, prohibitions on practices, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include operating procedures, treatment requirements and practices to control plant site runoff, and drainage from raw materials storage, spills, or leaks. Requirements for BMP-based pollution prevention plans generally applicable to all industries are discussed in more detail in the paper in the context of the U.S. Environmental Protection Agency's (EPA's) general permits for stormwater discharges associated with industrial activity.

In addition to generic BMPs or pollution prevention plans, industry- or activity-specific BMPs can be used. Table 1 provides a listing of industry-specific BMPs that the Washington State Department of Ecology has developed.[1]

### Diversion of Discharge to Treatment Plant

Where stormwater discharges contain significant amounts of pollutants that can be removed by a wastewater or sewage treatment plant, the stormwater discharge can be diverted to a wastewater treatment plant or sanitary sewage system. Such diversions must be coordinated with the operators of the sewage treatment plant and the collection system to avoid problems with either combined sewer overflows (CSOs), basement flooding, or wet weather operation of the treatment plant. Where CSO discharges, flooding or plant operation problems can result, and onsite storage followed by a controlled release during dry weather conditions may be considered.

### Traditional Stormwater Management Practices

In some situations, traditional stormwater management practices such as grass swales, catch basin design and maintenance, infiltration devices, unlined onsite retention and detention basins, regional controls (offsite retention or detention basins), and oil and grit separators can be applied to an industrial setting. Care must be taken, however, to evaluate the potential of many of these traditional devices for ground-water contamination. Other types of controls, such as secondary containment systems, can be used to prevent catastrophic events that can lead to surface or ground-water contamination via traditional stormwater measures. In some cases, it is appropriate to limit traditional stormwater management practices to those areas of the drainage system that generate stormwater with relatively low levels of pollutants (e.g., many rooftops, parking lots, etc.). At facilities located in northern areas of the country, snow removal activities may play an important role in a stormwater management program.

### Elimination of Pollution Sources/Water Reuse

In some cases, the elimination of a pollution source or water reuse may be the most cost-effective way to control pollutants in stormwater discharges associated with industrial activity. Options for eliminating pollution sources include reducing onsite air emissions affecting runoff quality, changing chemicals used at the facility, and modifying materials management practices such as moving storage areas into buildings. Water reuse involves collecting runoff and using it in a process or in some manner that does not release the pollutants in the stormwater to the environment. For example, many inorganic wood preserving facilities use drip pad runoff to dilute wood preserving fluids used in their processes. In some cases, it may be less expensive to store and treat stormwater for subpotable, industrial water supply purposes than purchasing municipal potable water.

## Clean Water Act Requirements

In 1972, the Clean Water Act (CWA) was amended to provide that the discharge of any pollutants to waters of the United States from a point source is unlawful, except where the discharge is authorized by an NPDES permit. The term "point source" is broadly defined to include "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, [or] channel, . . . from which pollutants are or may be discharged." Congress has specifically exempted agricultural stormwater discharges and return flows from irrigated agriculture from the definition of point source.

Most court cases have supported a broad interpretation of the term "point source" under the CWA. For example, the holding in *Sierra Club v. Abston Construction Co., Inc.,* 620 F 2d. 41 (5th Cir., 1980) indicates that changing the surface of land or establishing grading patterns on land where the runoff from the site ultimately is discharged to waters of the United States will result in a point source:

> A point source of pollution may be present where [dischargers] design spoil piles from discarded overburden such that, during periods of precipitation, erosion of spoil pile walls results in discharges into a navigable body of water by means of ditches, gullies and similar conveyances, even if the [dischargers] have done nothing beyond the mere collection of rock and other materials. . . . Nothing in the Act relieves [dischargers] from liability simply because the operators did not actually construct

[1] The document *Best Management Practices for the Use and Storage of Hazardous Materials* (14) also provides examples of industry-specific BMPs. The guidance addresses small mechanical repair facilities, large mechanical repair facilities, dry cleaning facilities, junkyards, photo processing facilities, print shops and silk screen shops, machine shops and airport maintenance facilities, boat manufacturing and repair facilities, concrete plants and mining facilities, agricultural facilities, paint manufacturers and distributors, and plastics manufacturers.

Table 1. Categories of Targeted Stormwater Controls Addressed in Puget Sound Guidance (13)

| Category | Targeted Stormwater Controls |
| --- | --- |
| Manufacturing facilities | Cement<br>Chemical<br>Concrete products<br>Electrical products<br>Food products<br>Glass products<br>Industrial machinery and equipment, trucks and trailers, aircraft, parts and aerospace, railroad equipment<br>Log storage and sorting yards, debarking<br>Metal products<br>Petroleum products<br>Printing and publishing<br>Rubber and plastic products<br>Ship and boat building and repair yards<br>Wood products<br>Wood treatment<br>Other manufacturing businesses |
| Transportation and communication | Airfields and aircraft maintenance<br>Fleet vehicle yards<br>Railroads<br>Private utility corridors<br>Warehouses and miniwarehouses<br>Other transportation and communication businesses |
| Wholesale and retail businesses | Gas stations<br>Recyclers and scrap yards<br>Restaurants/fast food<br>Retail general merchandise<br>Retail/Wholesale vehicle and equipment dealers<br>Retail/Wholesale nurseries and building materials<br>Retail/Wholesale chemicals and petroleum<br>Retail/Wholesale foods and beverages<br>Other retail/wholesale businesses |
| Service businesses | Animal care services<br>Commercial car and truck washes<br>Equipment repair<br>Laundries and other cleaning<br>Marinas and boat clubs<br>Golf and country clubs, golf courses, and parks<br>Miscellaneous services<br>Professional services<br>Vehicle maintenance and repair<br>Multifamily residences<br>Construction businesses |
| Pubic agencies | Public buildings and streets<br>Vehicle and equipment maintenance shops<br>Maintenance of open space areas<br>Maintenance of public stormwater facilities<br>Maintenance of roadside vegetation and ditches<br>Maintenance of public utility corridors<br>Water and sewer districts and departments<br>Port districts |
| Source controls | Fueling stations<br>Vehicle/Equipment washing and steam cleaning<br>Loading and unloading liquid materials<br>Liquid storage in aboveground tanks<br>Container storage of liquids, food wastes, and dangerous wastes<br>Outside storage of raw materials, byproducts, and finished products<br>Outside manufacturing activities<br>Emergency spill cleanup plans<br>Vegetation management/integrated pest management<br>Maintenance of storm drainage facilities<br>Locating illicit connections to storm drains |

those conveyances. . . . Conveyances of pollution formed either as a result of natural erosion or by material means, and which constitute a component of a drainage system may fit the statutory definition and thereby subject the operators to liability under the Act.

Although the definition of point source is very broad, before 1987 efforts under the NPDES program to control water pollution focused on controlling pollutants in discharges from publicly owned treatment works (POTWs) and industrial process wastewaters. The major exceptions to this are the 10 effluent limitation guidelines that EPA has issued for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

As part of the Water Quality Act of 1987, Congress added Section 402(p) to the CWA to require EPA to develop a comprehensive, phased program for regulated stormwater discharges under the NPDES program. One of the first priorities under the stormwater program was to develop NPDES requirements for stormwater discharges associated with industrial activity.

On November 16, 1990, EPA published the initial NPDES regulations under Section 402(p) of the CWA (see 55 FR 47990). The November 16, 1990, regulations:

- Defined the initial scope of the program by defining the terms "stormwater discharge associated with industrial activity" and large and medium "municipal separate storm sewer systems."
- Established permit application requirements.

The regulatory definition of the term "stormwater discharge associated with industrial activity" is provided at 40 CFR 122.26(b)(14) and addresses point source discharges of stormwater from eleven major categories of facilities. Table 2 summarizes these 11 major categories.

The NPDES regulations provided three options for submitting permit applications for stormwater discharges associated with industrial activity: 1) individual applications, 2) group applications for groups of similar industrial discharges, and 3) where an appropriate general permit has been issued, submittal of a notice of intent (NOI) to be covered by a general permit. The group application option is no longer available; EPA received over 1,100 group applications covering over 45,000 facilities. The Agency has organized these applications into the 32 industrial sectors shown in Table 3 and intends to develop guidance on issuing permits for the 32 industrial sectors.

**Table 2. Summary of Classes of Industrial Facilities Addressed by Regulatory Definition of "Stormwater Discharge Associated With Industrial Activity"**

| Class | Description |
|---|---|
| (i) | Facilities subject to stormwater effluent limitations guideline, new source performance standards, or toxic pollutant effluent standards (see 40 CFR Subpart N) |
| (ii) | Manufacturing facilities classified as Standard Industrial Classification (SIC) 24 (except 2434), 26 (except 265 and 267), 28 (except 283), 29, 311, 32 (except 323), 33, 3441, and 373 |
| (iii) | Active and inactive mining operations classified as SIC 10-14 |
| (iv) | Hazardous waste treatment, storage, or disposal facilities that are operating under interim status or a permit under Subtitle C of RCRA |
| (v) | Landfills, land application sites, and open dumps that receive industrial wastes |
| (vi) | Recycling facilities, including metal scrapyards, battery reclaimers, salvage yards, and automobile junkyards |
| (vii) | Steam electric power generating facilities |
| (viii) | Transportation facilities classified as SIC 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171, which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations |
| (ix) | Sewage treatment plants with a design flow of 1.0 million gal/day or more or required to have an approved pretreatment program |
| (x) | Construction activities except operations that result in the disturbance of less than 5 acres of total land area and that are not part of a larger common plan of development or sale |
| (xi) | Facilities under SIC 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, and 4221-25 (and which are not otherwise included within categories (i)-(x)) |

**Table 3. Industrial Sectors Identified in NPDES Group Application Process**

| Sector | SIC Codes/Activities Represented | Number of Facilities |
|---|---|---|
| 1 | SIC 24—Lumber and Wood Products | 2,640 |
| 2 | SIC 26—Paper and Allied Products | 1,023 |
| 3 | SIC 28—Chemicals and Allied Products | 1,498 |
| 4 | SIC 29—Petroleum Refining and Related Industries | 2,245 |
| 5 | SIC 32—Stone, Clay, Glass, and Concrete Products | 4,786 |
| 6 | SIC 33—Primary Metal Industries | 730 |
| 7 | SIC 10—Metal Mining | 188 |
| 8 | SIC 12—Coal Mining | 495 |
| 9 | SIC 13—Oil and Gas Extraction | 457 |
| 10 | SIC 14—Mining and Quarrying of Nonmetallic Minerals | 2,437 |
| 11 | Hazardous Waste Treatment Storage or Disposal Facilities | 77 |

**Table 3. Industrial Sectors Identified in NPDES Group Application Process (continued)**

| Sector | SIC Codes/Activities Represented | Number of Facilities |
|---|---|---|
| 12 | Industrial Landfills, Land Application Sites, and Open Dumps | 1,430 |
| 13 | SIC 5015—Used Motor Vehicle Parts | 2,009 |
| 14 | SIC 5093—Scrap and Waste Materials | 1,688 |
| 15 | Steam Electric Power Generating Facilities | 162 |
| 16 | SIC 40—Railroad Transportation | 1,024 |
| 17 | SIC 41—Local and Suburban Transit and Interurban Highway Passenger Transportation<br>SIC 42—Motor Freight Transportation<br>SIC 43—United States Postal Service | 13,089 |
| 18 | SIC 44—Water Transportation | 368 |
| 19 | SIC 3731—Ship Building and Repairing<br>SIC 3732—Boat Building and Repairing | 498 |
| 20 | SIC 45—Air Transportation | 1,581 |
| 21 | SIC 5171—Petroleum Bulk Stations and Terminals | 131 |
| 22 | Domestic Wastewater Treatment Plants | 1,249 |
| 23 | SIC 20—Food and Kindred Products<br>SIC 21—Tobacco Products | 2,608 |
| 24 | SIC 22—Textile Mill Products<br>SIC 23—Apparel and Other Finished Products Made From Fabrics and Similar Materials | 872 |
| 25 | SIC 25—Furniture and Fixtures | 339 |
| 26 | SIC 27—Printing, Publishing, and Allied Industries | 65 |
| 27 | SIC 30—Rubber and Miscellaneous Plastic Products | 190 |
| 28 | SIC 31—Leather and Leather Products | 61 |
| 29 | SIC 34—Fabricated Metal Products<br>SIC 391—Jewelry, Silverware, and Plated Ware | 965 |
| 30 | SIC 35—Industrial and Commercial Machinery<br>SIC 37—Transportation Equipment | 935 |
| 31 | SIC 36—Electronic Components<br>SIC 357—Computer and Office Equipment<br>SIC 38—Measuring, Analyzing, and Control Instruments; Photographic and Optical Goods, Watches, and Clocks | 14 |
| 32 | SIC—Miscellaneous Manufacturing Industries | 769 |

## Long-Term Strategy

Many of the initial concerns regarding the NPDES stormwater program focused on adapting the NPDES permit program to effectively address the large number of stormwater discharges associated with industrial activity. In response to these concerns, EPA developed a strategy for permitting stormwater discharges associated with industrial activity that will serve as a foundation for future program development and technology transfer. The strategy consists of two major components: a tiered framework for developing permitting priorities and a framework for the development of state stormwater management plans.

### *Permitting Priorities*

Under the strategy, most stormwater permitting activities are described in terms of the following four classes of activities:

- *Tier I—Baseline permitting:* One or more general permits will be developed initially to cover the majority of stormwater discharges associated with industrial activity.
- *Tier II—Watershed permitting:* Facilities within watersheds shown to be adversely affected by stormwater discharges associated with industrial activity will be targeted for individual or watershed-specific general permits.
- *Tier III—Industry-specific permitting:* Specific industry categories will be targeted for individual or industry-specific general permits.
- *Tier IV—Facility-specific permitting:* A variety of factors will be used to target specific facilities for individual permits.

These four classes of activities will be implemented over time and will reflect priorities within given states. In most states, Tier I activities will be the starting point. Initially, the coverage of the baseline permits will be broad. As priorities and risks within the state are evaluated, however, classes of stormwater discharges or individual stormwater discharges will be identified for Tier II, III, or IV permitting activities.

### *State Stormwater Management Programs*

State stormwater management programs are to provide, among other things, a description of NPDES permit issuing activities for stormwater discharges associated with industrial activity, including categories of industrial activity that are being considered for industry-specific general permits. These plans will assist EPA in developing technology transfer activities with other states, evaluating states' progress in implementing stormwater permitting activities, and identifying both successes and difficulties with ongoing program implementation.

## EPA's Baseline General Permits

Consistent with the long-term permit issuance strategy, EPA published Tier I general permits, which potentially could apply to the majority of stormwater discharges associated with industrial activity located in 12 states on

September 9, 1992, and September 25, 1992 (see 57 FR 41236 and 57 FR 44438). The 12 states where the EPA general permits apply are Alaska, Arizona, Florida, Idaho, Louisiana, Maine, Massachusetts, New Hampshire, New Mexico, Oklahoma, South Dakota, and Texas. Other states have authorized NPDES state programs, and the state issues NPDES permits instead of EPA.

Consolidating many sources under a general permit greatly reduces the administrative burden of issuing permits for stormwater discharges associated with industrial activity. Several advantages to this approach are:

- Pollution prevention measures and/or BMPs are established for discharges covered by the permit.
- Facilities whose discharges are covered by the permit are certain of their legal responsibilities and have an opportunity to comply with the CWA.
- EPA and authorized NPDES states will begin to collect and review data on stormwater discharges from priority industries, thereby supporting subsequent permitting activities.
- The public, including municipal operators of municipal separate storm sewers, will have the opportunity to review data and reports developed by industrial permittees pursuant to NPDES requirements.
- The baseline permits will provide a basis for coordinating 1) requirements for stormwater discharges associated with industrial activity with 2) requirements of municipal stormwater management programs in permits for discharges from municipal separate storm sewer systems.
- The baseline permits will provide a basis for bringing selected enforcement actions.
- The baseline permit, along with state stormwater permitting plans, will provide a focus for public comment on draft permits and subsequent phases of the permitting strategy for stormwater discharges.

The Agency believes that Tier I permits can establish the appropriate balance between monitoring requirements and implementable controls that will initiate facility-specific controls and provide sufficient data for compliance monitoring and future program development.

## Permit Requirements

The major requirements of EPA's Tier I stormwater general permits are notification requirements, requirements for stormwater pollution prevention plans, and special requirements for selected facilities.

### *Notification Requirements*

The general permits require the submittal of an NOI by the discharger before the authorization of discharges. In addition, operators of stormwater discharges that discharge through a large or medium municipal separate storm sewer system must, in addition to submitting an NOI to the Director, submit a copy of the NOI to the municipal operator of the system receiving the discharge.

### *Tailored Pollution Prevention Plan Requirements*

All facilities covered by EPA's general permits must prepare and implement a stormwater pollution prevention plan. These tailored requirements allow the implementation of site-specific measures that address features, activities, or priorities for control associated with the identified stormwater discharges. The approach taken allows the flexibility to establish controls that can appropriately address different sources of pollutants at different facilities.

The pollution prevention approach adopted in the general permits focuses on two major objectives: 1) to identify sources of pollution potentially affecting the quality of stormwater discharges from the facility, and 2) to describe and ensure implementation of practices to minimize and control pollutants in stormwater discharges.

The stormwater pollution prevention plan requirements in the general permits are intended to facilitate a process whereby the operator of the industrial facility thoroughly evaluates potential pollution sources at the site and selects and implements appropriate measures to prevent or control the discharge of pollutants in stormwater runoff. The process involves the following four steps:

- Formation of a team of qualified plant personnel responsible for preparing the plan and assisting the plant manager in its implementation.
- Assessment of potential stormwater pollution sources.
- Selection and implementation of appropriate management practices and controls.
- Periodic evaluation of the ability of the plan to prevent stormwater pollution and comply with the terms and conditions of this permit.

This process is shown in Figure 1. A complete description of this process can be found in U.S. EPA (15).

#### Pollution Prevention Team

As a first step in the process of developing and implementing a stormwater pollution prevention plan, permittees must identify a qualified individual or team of individuals to be responsible for developing the plan and assisting the facility or plant manager in its implementation. When

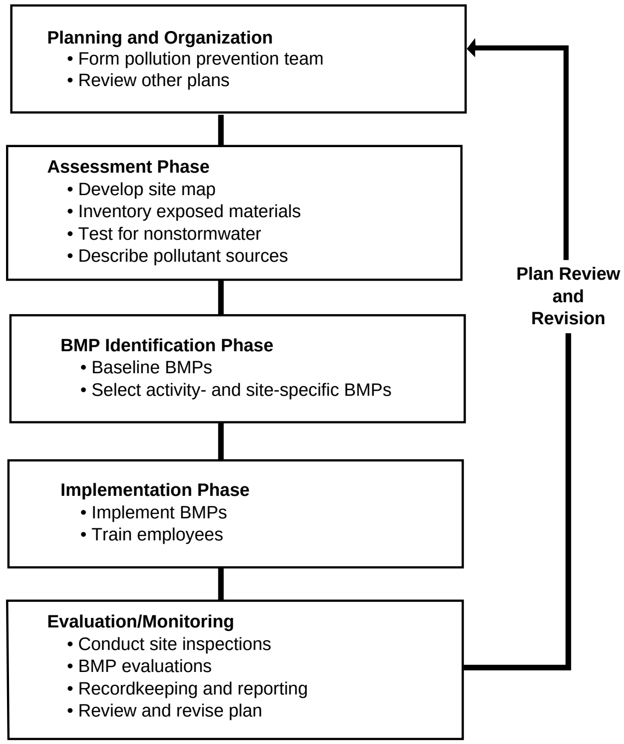


**Figure 1. Pollution prevention plan process.**

selecting members of the team, the plant manager should draw on the expertise of all relevant departments within the plant to ensure that all aspects of plant operation are considered. The plan must clearly describe the responsibilities of each team member as they relate to specific components of the plan. In addition to enhancing the quality of communication between team members and other personnel, clear delineation of responsibilities will ensure that a specified individual or group of individuals addresses every aspect of the plan.

## Description of Potential Pollution Sources

Each stormwater pollution prevention plan must describe activities, materials, and physical features of the facility that may contribute significant amounts of pollutants to stormwater runoff or, during periods of dry weather, result in pollutant discharges through the separate storm sewers or stormwater drainage systems. This assessment of stormwater pollution risk will support subsequent efforts to identify and set priorities for necessary changes in materials, materials management practices, or site features, as well as aid in the selection of appropriate structural and nonstructural control techniques. Plans must describe the site drainage, provide an inventory of exposed materials, describe significant spills and leaks that have occurred at the facility, and include existing sampling data.

Each pollution prevention plan must include a certification that discharges from the site have been tested or evaluated for the presence of nonstormwater discharges. The certification must describe possible significant sources of nonstormwater, the results of any test and/or evaluation conducted to detect such discharges, the test method or evaluation criteria used, the dates on which tests or evaluations were performed, and the onsite drainage points directly observed during the test or evaluation. Acceptable test or evaluation techniques are discussed earlier in this paper.

The description of potential pollution sources culminates in a narrative assessment of the risk potential that sources of pollution pose to stormwater quality. This assessment should clearly point to activities, materials, and physical features of the facility that have a reasonable potential to contribute significant amounts of pollutants to stormwater. Any such activities, materials, or features must be addressed by the measures and controls subsequently described in the plan. In conducting the assessment, the facility operator must consider loading and unloading operations, outdoor storage activities, outdoor manufacturing or processing activities, significant dust or particulate generating processes, and onsite waste disposal practices. The assessment must list any significant pollution sources at the site and identify the pollutant parameter or parameters (i.e., biochemical oxygen demand, suspended solids, etc.) associated with each source.

## Measures and Controls

Following completion of the source identification and assessment phase, the permittee must evaluate, select, and describe the pollution prevention measures, BMPs, and other controls that the facility will implement. BMPs include processes, procedures, schedules of activities, prohibitions on practices, and other management practices that prevent or reduce the discharge of pollutants in stormwater runoff.

The plan requirements emphasize the implementation of pollution prevention measures that reduce possible pollutant discharges at the source. Source reduction measures include, among others, preventive maintenance, chemical substitution, spill prevention, good housekeeping, training, proper materials management, material segregation or covering, water diversion, and dust control. The remaining classes of BMPs, which involve recycling or treatment of stormwater, allow the reuse of stormwater or attempt to lower pollutant concentrations before discharge.

The pollution prevention plan must include a schedule specifying the time or times during which each control or practice will be implemented. In addition, the plan should discuss ways in which the controls and practices relate to one another and, when taken as a whole, produce an integrated and consistent approach for preventing or controlling potential stormwater contamination problems. The portion of the plan that describes the measures and controls must address the following minimum components:

- *Good housekeeping:* Good housekeeping involves using common sense to identify ways to maintain a clean and orderly facility and keep contaminants out of separate storm sewers. It includes establishing protocols to reduce the possibility of mishandling chemicals or equipment, and training employees in good housekeeping techniques.
- *Preventive maintenance:* Permittees must develop a preventive maintenance program that involves regular inspection and maintenance of stormwater management devices and other equipment and systems. The program description should identify the devices, equipment, and systems that will be inspected; provide a schedule for inspections and tests; and address appropriate adjustment, cleaning, repair, or replacement of devices, equipment, and systems. For stormwater management devices such as catch basins and oil/water separators, the preventive maintenance program should provide for periodic removal of debris to ensure that the devices are operating efficiently.
- *Spill prevention and response procedures:* Based on an assessment of possible spill scenarios, permittees must specify appropriate material handling procedures, storage requirements, containment or diversion equipment, and spill cleanup procedures that will minimize the potential for spills and in the event of a spill enable proper and timely response. Areas and activities that typically pose a high risk for spills include loading and unloading areas, storage areas, process activities, and waste disposal activities. These activities and areas, and their accompanying drainage points, must be described in the plan. For a spill prevention and response program to be effective, employees should clearly understand the proper procedures and requirements and have the equipment necessary to respond to spills.
- *Inspections:* Qualified facility personnel must be identified to inspect designated equipment and areas of the facility at appropriate intervals specified in the plan. A set of tracking or followup procedures must be used to ensure that appropriate actions are taken in response to the inspections.
- *Employee training:* The pollution prevention plan must describe a program for informing personnel at all levels of responsibility of the components and goals of the stormwater pollution prevention plan. Where appropriate, contractor personnel also must be trained in relevant aspects of stormwater pollution prevention.
- *Recordkeeping and internal reporting procedures:* The pollution prevention plan must describe procedures for developing and retaining records on the status and effectiveness of plan implementation. At a minimum, records must address spills, monitoring, and inspection and maintenance activities. The plan also must describe a system that enables timely reporting of stormwater management-related information to appropriate plant personnel.
- *Sediment and erosion control:* The pollution prevention plan must identify areas that, due to topography, activities, soils, cover materials, or other factors, have a high potential for significant soil erosion. The plan must identify measures that will be implemented to limit erosion in these areas.
- *Management of runoff:* The plan must contain a narrative evaluation of the appropriateness of traditional stormwater management practices (i.e., practices other than those that control pollutant sources) that divert, infiltrate, reuse, or otherwise manage stormwater runoff to reduce the discharge of pollutants. Appropriate measures may include, among others, vegetative swales, collection and reuse of stormwater, inlet controls, snow management, infiltration devices, and wet detention/retention basins.

Based on the results of the evaluation, the plan must identify practices that the permittee determines to be reasonable and appropriate for the facility. The plan also should describe the particular pollutant source area or activity to be controlled by each stormwater management practice. Reasonable and appropriate practices must be implemented and maintained according to the provisions prescribed in the plan.

In selecting stormwater management measures, it is important to consider the potential effects of each method on other water resources, such as ground water. Although stormwater pollution prevention plans primarily focus on stormwater management, facilities must also consider potential ground-water pollution problems and take appropriate steps to avoid adversely affecting ground-water quality. For example, if the water table is unusually high in an area, an infiltration pond may contaminate a ground-water source unless special preventive measures are taken. Under EPA's July 1991 Ground Water Protection Strategy, states are encouraged to develop comprehensive state ground-water protection programs (CSGWPP). Efforts to control stormwater should be compatible with state ground-water objectives as reflected in CSGWPPs.

### Comprehensive Site Compliance Evaluation

The stormwater pollution prevention plan must describe the scope and content of comprehensive site inspections that qualified personnel will conduct to 1) confirm the accuracy of the description of potential pollution sources contained in the plan, 2) determine the effectiveness of the plan, and 3) assess compliance with the terms and conditions of the permit. The plan must indicate the frequency of such evaluations, which in certain cases must be at least once a year.

Material handling and storage areas and other potential sources of pollution must be visually inspected for evidence of actual or potential pollutant discharges to the drainage system. Inspectors also must observe erosion controls and structural stormwater management devices to ensure that each is operating correctly. Equipment needed to implement the pollution prevention plan, such as that used during spill response activities, must be inspected to confirm that it is in proper working order. The results of each site inspection must be documented in a report signed by an authorized company official.

Based on the results of each inspection, the description of potential pollution sources and the measures and controls in the plan must be revised as appropriate within 2 weeks after each inspection.

### Special Requirements for Selected Facilities

EPA's general permits also establish special requirements for selected classes of facilities. These include:

- *Sampling requirements:* Targeted classes of facilities are required to monitor their stormwater discharges for specified parameters. Facilities that are a member of a targeted class but that can certify that they do not have materials or equipment exposed to precipitation are not required to monitor. This is intended to provide facilities with an incentive to eliminate exposure to precipitation.
- *EPCRA facilities:* Certain facilities that are subject to reporting requirements under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) because they manufacture or use large amounts of toxic chemicals are subject to special requirements under the NPDES general permits. These special requirements include provisions that are similar to spill prevention, countermeasure, and control (SPCC) plan requirements, and include provisions for secondary containment or equivalent controls for liquid storage areas. In addition, a professional engineer (PE) must inspect the site, review the plan, and certify that the stormwater pollution prevention plan has been prepared in accordance with good engineering practices.
- *Salt piles:* Salt piles must be enclosed or covered to prevent exposure to precipitation.
- *Coal pile runoff:* The permit establishes numeric effluent limitations for coal pile runoff.

### Municipal Role in Implementation

The NPDES stormwater program establishes a permit approach that envisions complementary, cooperative efforts by the permit-issuing agency and municipal operators of large and medium municipal separate storm sewer systems to develop programs that result in controls on pollutants in stormwater discharges associated with industrial activity that discharge through municipal systems.

Under the complementary permit approach, stormwater discharges associated with industrial activity that discharge through large and medium municipal separate storm sewer systems are required to obtain permit coverage. Permits for these discharges will establish requirements (such as pollution prevention requirements or monitoring) for industrial operators. Any records, reports, or information obtained by the NPDES permit-issuing authority as part of the permit implementation process, including site-specific stormwater pollution prevention programs that are developed pursuant to the draft general permit, are available to municipalities. This will assist municipalities in reviewing the adequacy of such requirements and developing priorities among industrial stormwater sources. In addition, these permits provide a basis for enforcement actions directly against the owner or operator of stormwater discharges associated with industrial activity.

A second permit, issued to the operator of the large or medium municipal separate storm sewer, establishes the responsibilities of the municipal operators in controlling pollutants from stormwater associated with industrial activity that discharges through their systems. Municipal programs to reduce pollutants in industrial site runoff specifically will address municipal responsibilities in controlling pollutants from industrial facilities. In addition, programs to identify and control nonstormwater discharges to municipal separate storm sewer systems will in many cases focus on industrial areas because these areas often have a significant potential for illicit connections, spills, and improper dumping.

Municipal operators of these systems can assist NPDES permit issuing authorities:

- By identifying priority stormwater discharges associated with industrial activity to their systems.
- In inspecting facilities and reviewing and evaluating stormwater pollution prevention plans that industrial facilities are required to develop under the draft general permit.
- In compliance efforts regarding stormwater discharges associated with industrial activity to their municipal systems.

A pilot program conducted by municipalities in the Santa Clara Valley illustrates how a municipality can work with an NPDES authority to control pollutants in stormwater discharges associated with industrial activities. (A more complete description of the pilot program and its findings is provided in the Santa Clara Valley Nonpoint Source Pollution Control Program [3]). One of the major goals of the program was to reduce discharges to storm drains of dry- and wet-weather heavy metals that result from activities such as processing, storage, and maintenance activities conducted at industrial sites. Components of the program included the following:

- Municipalities developed industrial inspection and illegal dumping/illicit connection programs to ensure that activities focus on priority industries.
- Monitoring requirements were established in the California NPDES general permit for industries. Municipalities evaluated monitoring data collected by priority industries.
- The California NPDES general permit allowed for exemption for industries from monitoring where the municipality provides certification that the industry pollution prevention plan is adequate.
- Municipalities developed industry specific guidance.[2]
- Municipalities implemented a “Clean Bay Business” award program.
- Market-based incentives were considered, such as trading reductions from car pooling and telecommunication programs for pretreatment requirements.

Key findings of the pilot programs identified the following components needed for a successful program:

- Hands-on field training conducted by an experienced industrial inspector.
- Classroom training on industrial stormwater requirements and on methods of communicating with facility managers.
- Classroom training on other related industrial regulatory programs (e.g., HAZMAT, pretreatment).
- A reference manual on the regulations and local legal authority.
- Adequate legal authority to allow site access and take progressive enforcement actions.
- Prioritizing facilities based on existing information before conducting inspections.
- Advance communications, in the form of a letter, to industries before conducting the inspections.
- A plan for followup actions, including enforcement, where necessary.

[2]See *California Storm Water Best Management Practice Handbook: Industrial/Commercial* (16), which addresses how to prepare a stormwater pollution prevention plan and how to select BMPs. The guidance also addresses source controls for nonstormwater discharges; vehicle and equipment fueling; vehicle and equipment washing and steam cleaning; vehicle and equipment maintenance and repair; outdoor loading/unloading of materials; outdoor container storage of liquids; outdoor process equipment operations and maintenance; outdoor storage of raw materials, products, and byproducts; waste handling and disposal; contaminated or erodible surface areas; building and grounds maintenance; building repair; remodeling and construction; and overwater activities. In addition, the guidance covers treatment control BMPs and measuring BMP performance.

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# *The Role of Education and Training in the Development of the Delaware Sediment and Stormwater Management Program*

**Frank M. Piorko and H. Earl Shaver**
**Delaware Department of Natural Resources and Environmental Control, Dover, Delaware**

On May 31, 1990, the General Assembly of the State of Delaware enacted new legislation on stormwater management and placed it within the revised framework of the state's sediment control law to emphasize the integral relationship between the two programs. Governor Castle signed the legislation into law at a public ceremony on June 15, 1990. The effective date of the regulations was January 23, 1991. Program implementation was initiated on July 1, 1991.

The role of education and training in the development and implementation of Delaware's sediment and stormwater program was recognized at the legislative onset. The educational effort continued through the evolution, development, and promulgation of the regulations and remains an essential component of program strategy. The sediment and stormwater regulations are specific as to the training requirements and opportunities for education that are to be provided for contractors, construction review/inspection personnel, and plan design professionals.

This paper discusses the education and training accomplishments to date, their value to successful program inauguration, and specific training objectives being developed to meet the requirements of the new law and regulations in Delaware.

## Background

The State of Delaware has had an erosion and sediment control program since 1978. That program was only marginally successful due to budget and personnel limitations. Environmentally oriented initiatives in other states and within the federal government have since provided an impetus for the Department of Natural Resources and Environmental Control (DNREC) to attempt program improvements with respect to sediment control and stormwater management.

In 1989, DNREC representatives conducted onsite reviews of the existing sediment control program to document program effectiveness. It was readily apparent that too few resources were devoted to a program that lacked legislative and regulatory authority. The site problems were recorded through slide documentation so that a public education program could be developed that clearly showed the need for program improvements.

At the same time, DNREC, in association with local conservation districts, was considering the need for a statewide stormwater management program that considered water quantity and water quality requirements. Fortunately (or unfortunately, depending on the perspective), during the summer of 1989, Delaware had several severe flooding events that reinforced the concept that the state needed a stormwater management program that would prevent existing problems from getting worse.

Delaware does not have a strong environmental lobby group to advocate the passage of new environmental programs, so DNREC has developed a consensus-style approach to get legislation and subsequent regulations accepted by the legislative bodies and the regulated community.

## Legislative Process

As the legislation was developed, DNREC sponsored two workshops at which the concept behind the proposed legislation was discussed in a public forum accompanied by slide presentations. The slide presentation focused on problem identification, the proposed state program to address the problems, and the degree to which, in the opinion of DNREC, the sediment and stormwater program was going to evolve. Individual meetings were held with contractors' associations, engineering consultants, land developers, and the general public.

In addition to those workshops and meetings, presentations were made to legislative committees in an informal setting so that individual committee members would have a basic understanding of the need for legislation.

The proposed legislation passed through a state senate committee and the full senate in only 2 days, with not one negative vote. The passage of the legislation through two committees in the state house of representatives and the full house took approximately 1½ months and again received no negative votes. The educational process prior to submission of the legislation and during the legislative process was so successful that not one affected group submitted comments that were in opposition to the legislation. The legislation passed through three committees and two houses unanimously. The legislation was signed into law by Governor Castle in a public ceremony on June 15, 1990.

## Regulatory Process

The legislation has several components that specifically address education and training, but one component critical to the process of regulation adoption was the requirement in the law that the regulations were to be developed with the assistance of a regulatory advisory committee. Recognizing the need for program consensus, DNREC placed the regulatory advisory committee requirement within the legislation so that the affected entities would participate in the regulatory process.

The regulatory advisory committee was composed of representatives of 20 organizations representing such groups as contractors, developers, consulting engineers, utility companies, local governments, and conservation districts. DNREC prepared drafts of the regulations prior to meetings. Each section, subsection, paragraph, sentence, and word that was proposed for the regulations was subject to the scrutiny of the regulatory review committee. Each member of the committee did not have to approve all aspects of the regulations, but rather the committee needed to substantially concur. Eight full committee meetings were held, and through the meeting process committee members could understand the rationale behind the various regulatory requirements. As a result, the committee members substantially concurred on all aspects of the regulations. In fact, committee members tended to become advocates of the regulations when they were published for public input.

In addition to the regulatory review committee process, meetings were also held with any interested individual or entity. Once the regulations were in a rough state of completion, three public workshops were held around the state to solicit input from a broader range of interests than just those represented by the regulatory review committee. The input received during this public review process was limited, but the informal public process prepared people for what was intended in the regulations so that any significant opposition to any of the requirements could be addressed before the formal regulation adoption process.

On the basis of the input received from the workshops, DNREC initiated formal regulation adoption procedures with no major changes to the body of the regulations. Announcements were placed in newspapers regarding DNREC's intentions, and a formal public hearing was held on January 16, 1991. Due to the consensus-building process, in which the regulated community participated in developing the regulations, not one adverse comment was received during the public hearing process. The entire public hearing took less than 15 minutes, as there were no questions or comments due to public awareness of the regulations' contents.

The entire process of legislative and regulatory development and approval clearly demonstrates that a consensus-building approach to environmental requirements may be an effective means of obtaining the programmatic infrastructure needed to implement an effective program. In large part due to the strong involvement of the regulated community, there is a significant effort in the law and regulations regarding education and training of contractors, inspectors, consultants, and the general public. It is the position of the authors that environmental programs can only be effective if the regulated community is involved in program development and evolution, recognizes the program need, and understands and accepts their obligations under the regulatory requirements. The individual educational and training obligations under the law and regulations are discussed as they affect the overall sediment and stormwater program.

## Delaware Sediment and Stormwater Contractor Certification Program

During the development of the Delaware Sediment and Stormwater Regulations, a provision was made to provide for mandatory training and certification of individuals performing sediment and stormwater related construction. Section 13 of the regulations states that "After July 1, 1991, any applicant seeking sediment and stormwater plan approval shall certify to the appropriate plan approval agency that all responsible personnel involved in the construction project will have a certificate of attendance at a Departmental sponsored or approved training course for the control of sediment and stormwater, before initiation of land-disturbing activity."

"Responsible personnel" means any foreman or superintendent who is in charge of onsite clearing and land-disturbing activities for sediment and stormwater control associated with a construction project.

"Land-disturbing activity" means a land change or construction activity for residential, commercial, silvicultural, industrial, and institutional land uses that may result in soil erosion from water or wind or movement of sediments or pollutants into state waters or onto lands in the state, or which may result in accelerated stormwater runoff including, but not limited to, clearing, grading, excavating, transporting, and filling of land.

### *Contractor Certification Program Development*

The development of the Contractor Certification Program was part of a general sediment and stormwater educational package funded by a Section 205 (G) grant under the Clean Water Act from the U.S. Environmental Protection Agency. Other tasks included a review of similar programs throughout the mid-Atlantic region, contracting for aerial photography of sites under construction, preparation of a portable soils exhibit, and identifying future training and educational needs. The grant tasks were carried out jointly through a memorandum of understanding between DNREC's Division of Water Resources and the New Castle Conservation District. A steering committee was formed in April 1990 and met seven times over the course of the following 9 months. The purpose of the committee was to provide input for the development and implementation of the grant tasks.

It was determined that the certification program was to use a slide presentation format since excellent documentation was already available and additional field slides were easily obtained. In addition to the field slides of sediment and stormwater construction practices, text and technical slides needed preparation. A local company was contracted to produce this material.

The certification program was developed with a 3½- to 4-hour time frame in mind. This would allow for morning or afternoon sessions, even occasional evenings, as necessary. Maryland has enjoyed success for many years in their sediment control training program using a similar format and time frame.

A 55-page narrative describing the slide presentation was developed and made available to the audience upon request. This was done to encourage attention to the slide presentation rather than preoccupation with taking notes. Finally, it was decided that participants should receive a durable plastic laminate card with the state logo and the individual's name and certification number imprinted on it. This would give the participants a tangible item to associate with the completion of the program.

### *Contractor Certification Program Implementation*

By the end of January 1991, the program was ready to be presented. Certain restrictions were placed upon class size in order to communicate most effectively. Optimal class size was 30 to 40 members. Limiting the class size meant that the program would have to be presented many times; therefore, by July 1, 1991, not all of the contractors needing to complete the certification program would have the opportunity to do so. The Sediment and Stormwater Regulations provide for interim certification if individuals notify DNREC of their intent to register for the next available course.

The certification program was designed for presentation in two ways. First, the conservation districts, counties, and other agencies given the responsibility of certain program elements would set up the programs in their own jurisdictions, giving them a chance to meet with the regulated community and explain local program requirements. Second, DNREC would present the program to any regulated company, business or organization if they could provide a suitable location and a minimum of 15 individuals to be trained. DNREC also provided training for DNREC staff and several hundred Delaware Department of Transportation inspectors, technical staff, and engineers.

Throughout the first 6 months of presentations, we were surprised and pleased not only with the response from the contractors but also from the engineers, consultants, and developers who wanted to attend the certification program. All told, from February 1991 until July 1991, DNREC presented the program on 37 occasions, certifying over 1,100 individuals from 300 companies and organizations.

As stated earlier, this was possible only with the assistance from the three state conservation districts, county governments, the Department of Transportation, and organizations such as the Associated Builders and Contractors and the Delaware Contractors Association. As of January 1, 1993, almost 2,000 individuals have completed this training.

Initially, a program quiz was developed not so much to grade the participants but to obtain feedback on the retention of the material being provided. A program evaluation was later substituted for the quiz so that we could determine if any changes or improvements should be made to the training program. A representative sample of 100 evaluations was compiled, the results of which appear in Figure 1. Most notable is that 96 percent of respondents would recommend this training (Question 7), and 86 percent wished to continue in this training (Question 8).

By continuing the Contractor Certification Program, not only are the requirements of the Delaware Sediment and Stormwater Regulations being met, but the knowledge gained by the participants in this program is being transferred to the field through proper construction practices.

## Delaware Certified Construction Reviewer Course

The Delaware Sediment and Stormwater Regulations also provide for special site inspection or review requirements under certain site conditions. Section 12 of the

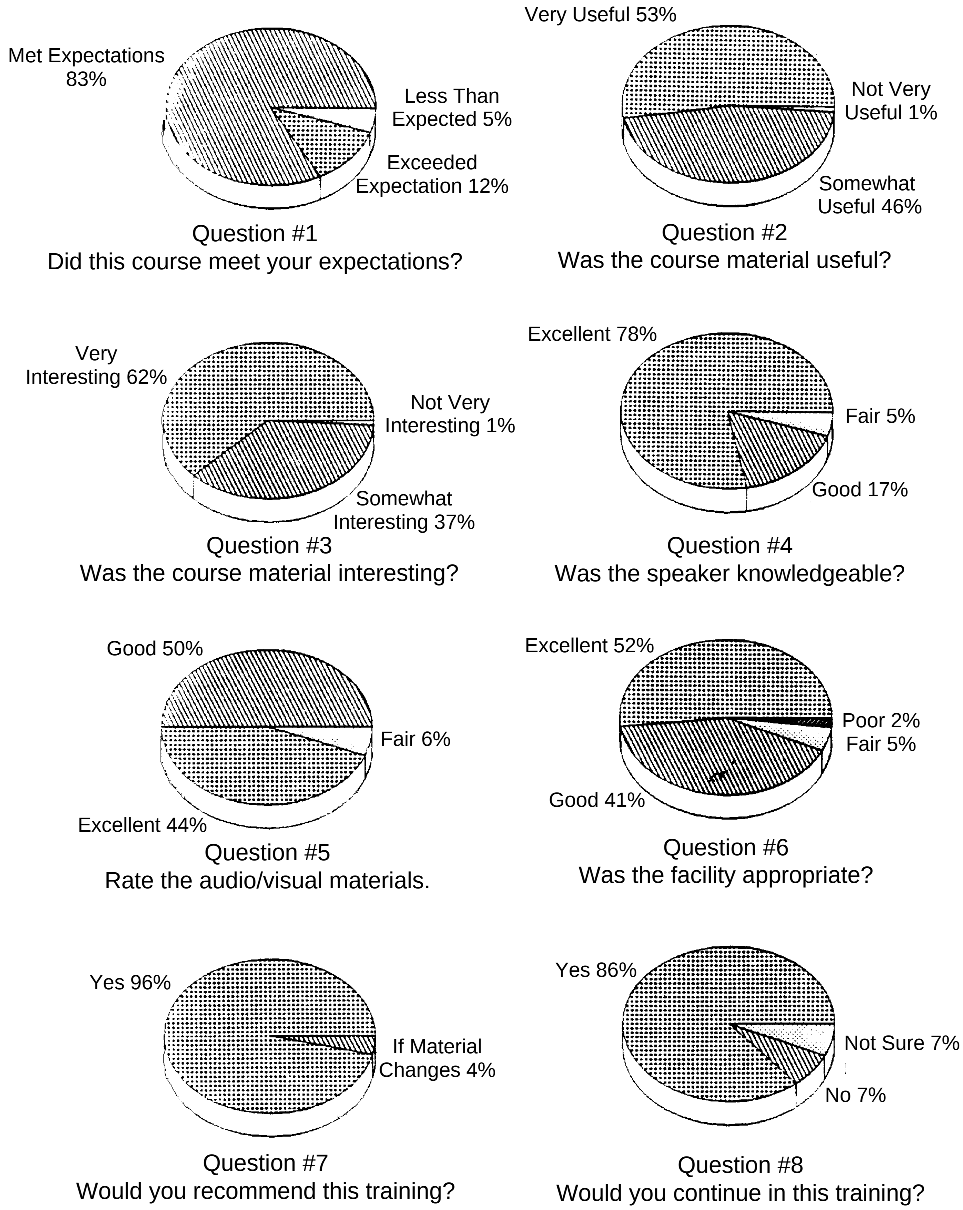


**Figure 1. Sediment and stormwater contractor certification program course evaluation.**

regulations identifies these site conditions that allow DNREC or the appropriate plan approval agency to require that a certified construction reviewer be present on site. Examples of site conditions that would warrant this requirement would be a site in excess of 50 acres of disturbed area or any site experiencing significant sediment and stormwater problems. The owner or developer of the site in these cases would be responsible for providing a certified construction reviewer for any or all parts of the construction phase as deemed necessary by the plan approval agency. The main responsibility of these individuals is to ensure the adequacy of construction pursuant to the approved sediment and stormwater management plan.

As with the Contractor Certification Program, DNREC has the responsibility to provide training to certify these construction reviewers. A formal Sediment and Stormwater Management Certified Construction Reviewer Course was developed in cooperation with Delaware Technical and Community College. Course material was developed to instruct participants in basic hydrology and hydraulics, soils, vegetative establishment, construction practices, plan preparation and implementation, inspection, enforcement, and maintenance. To instruct this course, over 20 professionals in the area of sediment and stormwater management were recruited, representing government agencies, private industry, and the consulting and engineering community.

The course format was developed to be presented in eight 3½-hour weekly sessions. An examination was developed and arrangements made with Delaware Technical and Community College for Continuing Education Credits to be issued.

We anticipated a lot of interest in this course offering, so registration was limited to one individual per company or organization. In addition to the private community, an attempt was made to include at least one individual that works for each agency responsible for delegation of sediment and stormwater program elements. In all, 85 seats were quickly filled for this course. The second time this course was offered, the class sessions were reduced to four all-day sessions. This seemed to suit the class participants' schedule better.

One important measure of success is the evaluation question that asked class participants to indicate whether the course did not meet, met, or exceeded expectations. The breakdown is as follows:

- 41 responses, or 74 percent of the class, stated that the course met their expectations.
- 12 responses, or 22 percent of the class, stated that the course exceeded their expectations.
- 2 responses, or 3.5 percent of the class, stated that the course did not meet their expectations.

The success of this program is directly attributable to the preparation of the speakers, the attentiveness of the class, and the hard work of the Delaware Sediment and Stormwater Program staff.

## Stormwater Management Technical Sessions

The engineering and design community in Delaware has also indicated the need for DNREC to present more design-oriented training in sediment and stormwater management. To date, there have been several workshops in U.S. Department of Agriculture Soil Conservation Service TR-55 and TR-20 hydrologic analyses sponsored by local conservation districts and enlisting the assistance of the Soil Conservation Service. DNREC recognizes the need to expand this basic training and make available more design-oriented training for the consultant community.

Coinciding with the development and release of the *Delaware Stormwater Management Design Manual* in the summer of 1993, training classes were scheduled to present this material in modules, as the manual was developed. This training will help ensure that stormwater management practices are designed to meet established minimum criteria.

## Summary

The education and training component of the Delaware Sediment and Stormwater Management Program is one of several areas of program development that will continue to respond to the needs of the regulated community. One obvious benefit in a small state like Delaware is that the efforts of a regulatory agency in providing education and training to the regulated community are recognized and appreciated. As previously discussed, the Sediment and Stormwater Management Program depends highly on interagency cooperation and communication with the businesses and industry involved. By maintaining education and training objectives as a high priority, DNREC will increase chances for program success.

# *Development and Implementation of an Urban Nonpoint Pollution Educational and Informational Program*

**Richard Badics**
**Washtenaw County Environmental Services Department,**
**Ann Arbor, Michigan**

## Abstract

Sampling, Abatement, Follow-up, Education, and Response (SAFER) was formed by the Washtenaw County's Environmental Interest Group on January 1, 1992. SAFER includes the county departments of Environmental Coordination, Environmental Services, Drain Commissioner, Planning, and Cooperative Extension, as well as the Soil Conservation District, Huron River Watershed Council, Ecology Center of Ann Arbor, and the Southeast Regional Groundwater Education Center. The purpose of SAFER is to "provide for coordination of water protection programs through inter- and intracounty agencies and group cooperation."

Education is a key element of SAFER. Four groups are targeted for education by SAFER: government, business and industry, community groups, and schools. SAFER members develop their own specific educational programs and materials. Through SAFER, these are coordinated to provide uniform and accurate information to targeted segments of the community. This avoids costly duplication of services.

To effectively deliver an educational program, the target audience must first be determined, then an analysis of existing educational programs must be made to build on past successes. Through this process, an approach is determined that is most likely to be successful. Prior to beginning the educational program, the establishment of an evaluation process is critical.

## Overview of Washtenaw County's SAFER Group

Sampling, Abatement, Follow-up, Education, and Response (SAFER) was formed by Washtenaw County's Environmental Issues Group on January 1, 1992. The Environmental Issues Group consists of departments within Washtenaw County government that indirectly or directly manage the environment of Washtenaw County. This provides the county with a coordinated approach to addressing environmental issues. The Environmental Issues Group is chaired by the Environmental Coordination Office. Other member groups within the Environmental Interest Group are the Sheriff's Department, Environmental Services, Emergency Management, Planning, Public Works, Drain Commissioner, and Cooperative Extension, as well as the county's Health Officer. This group meets monthly to discuss the status of county programming, pending state and federal legislation, "hot" environmental topics or issues, and strategic planning.

SAFER was formed as a work group of the Environmental Issues Group "to provide for coordinative water protection programs through inter- and intracounty agencies and group cooperation." SAFER consists of groups internal and external to Washtenaw County government that are involved in dealing with the county's ground and surface water. SAFER includes the county departments of Environmental Coordination, Environmental Services, Drain Commissioner, Planning, Cooperative Extension, Soil Conservation District, Huron River Watershed Council, and Ecology Center of Ann Arbor, as well as the Southeast Regional Groundwater Education Center (SER-GEM). During its first year of operation in 1992, the group focused on categorizing and compiling all current water quality programs and their products. The 1992 SAFER Directory compiled over 100 products addressing water quality issues within the county.

Education is a key element of SAFER. Four target groups for educational programs in SAFER are government, business and industry, community groups, and schools. The SAFER Educational Subcommittee in 1993 is compiling all educational programs and materials on water quality related issues, similar to the 1992 SAFER Directory. Through SAFER, educational materials are coordinated to provide current and accurate information to the community while avoiding costly duplication of services.

## Urban Nonpoint Pollution Education

The development and implementation of a nonpoint pollution educational and informational program is critical to a successful urban project. Public awareness of urban nonpoint pollution is relatively low, and the media tends to focus on health or environmental risks that are easy to define, such as AIDS or hazardous waste issues. Due to its nature, nonpoint pollution is harder to pinpoint. Urban nonpoint pollution prevention requires a long-term commitment to changing attitudes.

Urban nonpoint pollution can be directly attributed to people. We all contribute to it. People are accustomed to focusing on easier issues, where the blame can be attributed to activities outside their control. An example is auto safety. People are very concerned about vehicle safety when a manufacturing error is the cause, such as exploding gas tanks. These same people, however, are not as focused on actions that they control, such as wearing seat belts.

An environmental example is oil spills. A study by the Michigan Department of Natural Resources (MDNR) in 1989 found that more oil is illegally released into the environment in Michigan annually than was released in the Valdez tanker incident. Getting people to buy into the idea that they are a major part of the problem is a critical step in gathering their support and cooperation.

### *Target Audience*

Before an education information program can be developed, the target audience must be identified. A general educational approach will not change the habits of a wide range of target groups. Each targeted group must be analyzed independently to understand its particular needs and to develop specific actions it can take. Next, the various media options must be explored.

A multimedia approach enhances the opportunities of reaching larger segments within the target audience. For example, handing out flyers at a garden show will not reach several socioeconomic classes; a spot on a local radio station may be more appropriate. Some common public outreach materials are fact sheets, pamphlets, radio, television, newspapers, magazines, displays, models, posters, group presentations, and one-on-one or community events.

Using existing resources in your educational program is important. An educational program workshop for composting in the community could also be a forum for supplying information to the public on preventing urban nonpoint pollution through the proper application of fertilizers and use of environmentally friendly alternatives to pesticides. By networking with existing programs in the community, nonprofit programs will not compete for and confuse the audience.

### *Educational Gaps*

After analyzing current educational resources within the community, identify audiences and approaches not currently used. All targeted groups need to receive your message. Target groups in the community must "buy into" their contribution to nonpoint pollution and their ability to prevent or minimize it. Urban educational programs must be innovative, well conceived, multimedia, and coordinated with other educational programs in the community.

A large number of ongoing urban nonpoint education programs exist in communities throughout the country. These programs have been developed for various types of audiences. Prior to implementing a program "from scratch," review all ongoing programs. These can be found in EPA "News Notes," as well as through professional groups, conferences, and environmental publications. Regional EPA offices are also a valuable resource for finding suitable ongoing programs. Using existing programs saves time and money.

### *Program Evaluation*

An integral part of all educational programs is evaluation. Valuable time and resources can be wasted if information supplied to an audience is not effective. When developing the evaluation mechanism for the educational process, make sure the educational program focus enhances the overall water quality objectives. One way to evaluate the educational process is to apply Bennett's Hierarchy of Evidence for Program Evaluation. Bennett uses seven steps of evaluation. In an inverted scale, these steps are:

1. Inputs of program resources that are used to make the program work.
2. Activities which can include internal events, such as planning, or external events involving an audience.
3. Involvement of the target audience in activities, focusing on hands-on type activities.
4. The target audience's view of the program.
5. KASA change, or the change in **k**nowledge, **a**ttitudes, **s**kills, or **a**spirations of the audience.
6. Changes in behavior that result from the educational program.
7. End results that reflect the program's goals and objectives.

Many techniques can be used to measure the seven Bennett attributes. The basic who, what, where, and when questions are useful when establishing the specific evaluation technique.

Many books and guides can help in developing program evaluation. Studying these before finalizing an evaluation process is highly recommended. If there are time constraints or expertise is not available for evaluation, this component can be done by an outside party. The key is to establish the evaluation mechanism before implementing the educational program.

## Huron River Pollution Abatement Program

### *Overview*

The Huron River Pollution Abatement Project (HRPAP), which encompassed the urbanized area of Washtenaw County, was formed and implemented in 1986 by the county's Drain Commissioner's Office in conjunction with the Environmental Services Department. Public education was a major objective of the project. The educational program used by the HRPAP was designed after reviewing earlier area pilot water quality programs and their targeted community groups. The HRPAP focused on business, industry, community, and school groups.

### *Business/Industry*

The HRPAP conducted surveys and dye tests of facilities located in the urbanized areas of Washtenaw County. Staff interviewed facility owners and managers on their particular businesses and gained critical information about their operations. When a common need was found—for example, an owner unable to dispose of a certain type of waste—the project staff worked with the owner to resolve the problem. For example, many facility operators with oil separators were not familiar with separators and were unable to find a licensed waste hauler to service them. The HRPAP developed a maintenance guideline for the operators, contacted all local waste haulers, and developed a list of haulers that would service oil separators. This information was then distributed to all facilities with oil separators.

### *Community and Civic Group Education*

Over 200 educational presentations were made to the community during the HRPAP's 6 years. The HRPAP used various media to educate the community. One of the most effective was the local press. Articles concerning the HRPAP were published on an ongoing basis. Press releases noted significant events and common problems found within the community.

A second approach to outreach was through community events. Examples are the Ann Arbor City Art Fair and the Ypsilanti City Heritage Festival. These events attract hundreds of thousands of people. Display booths and pamphlets were developed for participating in these events. This became a forum for discussing water quality related issues one-on-one with the public.

### *School Education*

The HRPAP made its first school educational presentation to a third-grade class in 1988. Word of mouth led to over 25 presentations per year in six local school districts. HRPAP student interns with an educational background formulated lesson plans for different grade levels on nonpoint pollution and related topics, such as the water cycle and household hazardous waste.

In classrooms, educational programs concentrated on hands-on activities. Two water quality models were built. One electronic model, entitled "Pathways to Pollution," lights up various pollution pathways when the appropriate button is pushed. A second model is a transparent representation of a town showing the sanitary and storm sewer systems. The students place a dye into catch basins, floor drains, and toilets to observe the route the water takes directly to the stream or the wastewater treatment plant. This model has examples of both proper and improper connections.

## Conclusions

The majority of urban nonpoint pollution can be directly attributed to the activities of people. Most people are not aware of the impacts their routine activities at home and at work have on water quality. Education is a key component to improving urban water quality problems. Key target audiences in the community need to be identified, existing educational resources studied, educational program gaps identified, and an evaluation process included to measure a program's effectiveness.

The key to an educational program is to focus on practical activities that the target group can do to eliminate water pollution. A long-term, sustained educational effort leads to an increased awareness and respect for the interdependence of all elements in the ecosystem and for how individual activities affect them. This ultimately leads to a sense of mutual responsibility and a long-term commitment to continued environmentally sound actions.

## Acknowledgments

The author would like to acknowledge the support and help of Dr. Rebecca Head, Group Director, Environment and Infrastructure; Janis Bobrin, Drain Commissioner; Robert Blake, Director, Environmental Services; David Dean; H. Leon Moore; Jeffry Krcmarik; and David Wilson, as well as other members of SAFER.

# *Training for Use of New York's Guidelines for Urban Erosion and Sediment Control*

**Donald W. Lake, Jr.**
**U.S. Department of Agriculture,**
**Soil Conservation Service, Syracuse, New York**

## Introduction

New York State still does not have a statewide erosion and sediment control law. Unlike many of its neighboring states, New York continues to leave the initiation of such control to local units of government. Historically, counties, towns, and villages have enacted ordinances once a significant environmental accident has occurred. Jurisdiction occurs at the local level, with planning boards having approval authority to issue permits to develop. Because each board is dealing with its local area, the regulations and processes for gaining approval vary from locale to locale.

Technical standards for controlling erosion and sediment were developed by the Soil Conservation Service in March 1988 and issued as *New York Guidelines for Urban Erosion and Sediment Control*. This document provides design details and specifications for both temporary and permanent management practices, as well as resource-planning concepts. Known as the "Blue Book," the document provides consistency in the technical approach to erosion and sediment control plans for construction sites. It has been adopted by the New York State Department of Environmental Conservation and the U.S. Army Corps of Engineers, Buffalo District, as criteria for erosion and sediment control plans. The New York State Department of Transportation has incorporated many of its details into its highway design manual.

In April 1992, the New York State Department of Environmental Conservation (NYS-DEC), Division of Water, published *Reducing the Impacts of Stormwater Runoff From New Development*. This document establishes performance standards for stormwater management control in New York for projects requiring NYS-DEC review. Standards were set for both water quantity and water quality. Water quantity is addressed by requiring no greater discharges from the site after development than present before development for the 2-, 10-, and 100-year frequency storm events. Water quality is addressed by retaining the "first flush," which is defined as the greater of one-half inch of runoff or runoff resulting from a 1-year, 24-hour storm, from the land area for which the infiltration rate has been changed.

These two documents finally provide guidance for erosion and sediment control and stormwater management for local units of governments as well as regulatory agency staffs. Their use and application depends on what the site's size and resource constraints are and whether a local ordinance is in place. The local approval process, in communities with such a regulation, generally requires a formal review of the plan with its erosion and sediment control and stormwater management component by either the town or village engineer and a local soil and water conservation district staff person or health department official. Unfortunately, many of these individuals are unable to identify problems or lack the knowledge of design details to control sediment from the site.

Once a developer begins operations in the field, the building inspector, code enforcement officer, or health department official is responsible for inspecting the site for compliance to the approved plan as well as to ensure that the contractor maintains the installed practices. These field inspectors require training in the concepts of erosion and sediment control installation and maintenance.

## Clean Water Act Mandates

On October 1, 1992, stormwater regulations went into effect under the Clean Water Act that require individuals, agencies, and municipalities to apply for a National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharges from a variety of activities. New York State is a NPDES-delegated state, and the

Department of Environmental Conservation is administering this program through their State Pollutant Discharge Elimination System (SPDES) permit. One of the 11 categories covered in the regulations is construction activity. Under this activity, any site where 5 or more acres are disturbed must have an erosion and sediment control plan and a stormwater management plan. The 5-acre size limit has been challenged as arbitrary, and the size limit could be changed to 1 acre of disturbed area. A developer needs to file a Notice of Intent at least 48 hours before beginning operations to have "coverage." This notice is filed with the U.S. Environmental Protection Agency in Newington, Virginia. Under the regulations, copies of the erosion and sediment control plan and stormwater management plan are to be kept on site. Copies of each are also sent to the municipality that has jurisdiction. NYS-DEC does not want the notices or plans sent to its offices; they will not be reviewing or approving these plans. Who will? What will be the local impacts?

As a result of this mandate, many New York counties, towns, and villages will be receiving many erosion and sediment control and stormwater management plans. The majority of these units of government are still unaware of the requirements of the national program and of what their role is or should be. There is a great need for administrators, planners, and legislators to become aware of the program and the process. Technical staff need to learn the principles of planning, design, construction, and inspection for erosion and sediment control and stormwater management systems.

Positive aspects of the NYS-DEC approach to the program include the opportunity for local policy development, provisions for local ordinances, and the formation of interagency partnerships. Because NYS-DEC recognizes that authority should rest at the local level, communities have control over the quality of the natural resources in their backyards. Of course this may require additional staff or cooperation with other agencies to assist with implementation.

## Training Programs

Early efforts in erosion and sediment control began with awareness seminars at the local level. The seminars usually lasted 2 hours an evening for local officials involved in the site review and approval process. Recognizing problems, learning the planning steps, and becoming familiar with practices and guidelines were the limit of these seminars.

The complexity of requirements and the technical needs have increased dramatically due to recent mandates. The Soil Conservation Service, in cooperation with NYS-DEC and Syracuse University, has developed a tiered educational program in erosion and sediment control and stormwater management.

A 1-day seminar has been developed for planning board members, environmental management council members, legislators, and town boards, and has included legal advisors, consulting engineers, and other agency personnel responsible for environmental analysis. This agenda is included as Figure 1. This seminar stresses site planning through a slide presentation that demonstrates problems without control and shows practices necessary to maintain resources on the site. Stormwater management performance standards are reviewed in accordance with NYS-DEC criteria. This seminar is reinforced with two specific site examples. Attendees are asked to work in small design teams to design an erosion and sediment control plan for the first site. These same design teams are asked to critique the second site, which already has an erosion and sediment control plan. Thus, attendees go from designers to reviewers in applying their knowledge of these principles.

A 2-day workshop has been developed for the technical staffs of resource agencies, consulting engineers, local governments, and others with technical review or design responsibility (see Figure 2). This session begins with a quick overview of the principles of erosion and sediment control, then continues with a class exercise to design an erosion and sediment control plan for a development site while working in design teams of approximately four individuals. The afternoon of the first day is spent at a field site gathering specific resource information and data to design a detailed erosion and sediment control plan for the site. The design teams also compute and compare peak discharges for the site for predevelopment and postdevelopment conditions using Soil Conservation Service Technical Release 55, Urban Hydrology for Small Watersheds (TR-55). The session concludes with group presentations.

A 3-day short course with Syracuse University has been developed to address the specific technical needs of consulting engineers working with stormwater and erosion control systems. This tuition-based course provides for more indepth design of erosion and sediment control practices using a field site. Sizing stormwater detention basins is also required. In addition to the increased technical emphasis, additional speakers from state and local agencies provide a component on rules and regulations. Syracuse University awards two continuing education units for this course, which 57 people have completed to date. The agenda is included as Figure 3.

Urban Erosion Control and Stormwater Design (CIE 600) stands as a fully accredited 3-hour graduate level course in the Civil and Environmental Engineering Department at Syracuse University. It was taught for the first time in the 1992 fall semester and will be taught again this September. It was developed as a hands-on course that requires detailed designs for two projects, using field trips and six additional site review projects.

# EROSION AND SEDIMENT CONTROL SEMINAR
# AGENDA

| | |
|---|---|
| 8:30 AM | Registration |
| 9:00 AM | Introduction and Course Overview |
| 9:15 AM | Developing an Erosion and Sediment Control Plan<br>— Planning Considerations<br>— Factors That Influence Erosion<br>— Elements for a Sound Plan<br>— Vegetative and Structural Components<br>— Standards and Specifications |
| 11:00 AM | Site Example<br>— Develop Conceptual Erosion and Sediment Control Plans |
| 12:00 PM | **LUNCH (ON YOUR OWN)** |
| 1:00 PM | Site Review<br>— Critique an Erosion and Sediment Plan for a Specific Site |
| 3:30 PM | Wrap Up/Summary |
| 4:30 PM | Adjournment |

**Figure 1. Erosion and Sediment Control Seminar agenda.**

# EROSION AND SEDIMENT CONTROL WORKSHOP

# AGENDA

## First Day

| | |
|---|---|
| 8:30 AM | Registration |
| 9:00 AM | Introduction and Course Overview |
| 9:15 AM | Developing an Erosion and Sediment Control Plan<br>—Planning Considerations<br>—Factors That Influence Erosion<br>—Elements for a Sound Plan<br>—Vegetative and Structural Components<br>—Standards and Specifications |
| 11:00 AM | Site Example<br>—Develop Conceptual Erosion and Sediment Control Plans |
| 12:00 PM | **LUNCH (ON YOUR OWN)** |
| 1:00 PM | Design Session—Site-Specific Practices<br>—Temporary Swale<br>—Sediment Trap<br>—Urban Runoff |
| 2:30 PM | Field Problem—Design Teams<br>—Gather Data<br>—Develop Concepts in Field |
| 4:30 PM | Adjournment |

## Second Day

| | |
|---|---|
| 8:30 AM | Complete Group Designs |
| 10:00 AM | Design Critiques |
| 12:00 PM | **LUNCH (ON YOUR OWN)** |
| 1:00 PM | Design Session<br>—TR-55 Analysis for Structures<br>—Rock Outlet Protection<br>—Class Discussion |
| 3:00 PM | Wrap Up and Summary |
| 3:45 PM | Adjournment |

**Figure 2. Erosion and Sediment Control Workshop agenda.**

# SYRACUSE UNIVERSITY
# UNIVERSITY COLLEGE
# EROSION AND SEDIMENT CONTROL

## SHORT COURSE AGENDA
## April 28-30, 1992

### First Day

| | | |
|---|---|---|
| 9:00 AM | Registration and Coffee | Dr. Stephan Nix |
| | Introduction and Course Overview | |
| 10:00 AM | Legislation, Ordinances, and Regulatory Review Process | Mr. Robin Warrender<br>Mr. William Morton<br>Mr. Russell Nemecek |
| 11:00 AM | Developing Your Stormwater Management Plan and Practices | Mr. William Morton |
| 12:00 PM | Lunch | |
| 1:00 PM | Urban Hydrology and Flow Routing | Mr. Donald W. Lake, Jr. |
| 2:15 PM | Break | |
| 2:30 PM | Urban Hydrology and Flow Routing (continued) | |
| 4:30 PM | Adjourn | |

### Second Day

| | | |
|---|---|---|
| 8:00 AM | Developing Your Erosion Control Plan | Mr. Donald W. Lake, Jr. |
| 9:30 AM | Break | |
| 9:45 AM | Erosion and Sediment Control Practice Standards | Mr. Donald W. Lake, Jr. |
| 11:30 AM | Lunch (En Route to Field Site) | |
| 12:00 PM | Field Tour/Site Problems | Mr. Donald W. Lake, Jr. |
| 3:00 PM | Group Design Session | |
| 5:00 PM | Adjourn | |

### Third Day

| | | |
|---|---|---|
| 8:00 AM | Group Presentations and Critiques | |
| 10:00 AM | Break | |
| 10:15 AM | Group Presentations (continued) | |
| 11:45 AM | Wrap Up—Adjourn Short Course | Dr. Stephan Nix |
| 1:00 PM | Certified Professional Erosion Specialist Exam<br>Part II (Optional) | Mr. Donald W. Lake, Jr. |

**Figure 3. Erosion and Sediment Control short course agenda.**

In addition, the class participates in a town planning board meeting. Syllabus topics (see Figure 4) include manual and computer analyses of stormwater discharges and lectures by a plant materials specialist, a code enforcement officer, and governmental representatives dealing with rules and regulations. Twelve students enrolled in the first class, which was extremely well received by both students and the people who provided the example sites.

## Summary

Over 2,600 people have received training through 76 different seminars, workshops, short courses, and the graduate course since the training effort began in the fall of 1988. These tiered training sessions have evolved one after another based on needs at the local level. Leaders in the NYS-DEC recognized that benefits are local so training efforts should be local. This has led to interagency cooperative agreements between the U.S. Department of Agriculture, Soil Conservation Service, and NYS-DEC to bring training directly to the communities.

There is no sign of these training requests letting up. An average of 10 requests for the seminar sessions are made at the local level during the year. In addition, the proposed cooperative agreement for Fiscal Year 1994 between the Soil Conservation Service and NYS-DEC calls for five 1-day seminars, four 2-day workshops, four 2-day TR-55 hydrology workshops, and two short courses. The Syracuse University graduate course will be taught again this fall. Future projects also include workshops for New York State code enforcement officers, development of a field notebook for job superintendents, and field application courses for equipment operators. After all, equipment operators have the last word in installation.

We have come a long way, but we can see that challenges are still ahead of us to educate public planners, legislators, consultants, technical staff, and contractors in the use of sound erosion and sediment control and stormwater management practices to protect and enhance water quality and the environment.

## DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
## SYRACUSE UNIVERSITY

## CIE 600

## URBAN STORMWATER AND EROSION CONTROL DESIGN
## FALL 1992

| | |
|---|---|
| SCHEDULE: | Monday/Wednesday<br>6:15-7:45 PM<br>Peck Hall, University College |
| INSTRUCTOR: | Donald W. Lake, Jr., PE<br>State Conservation Engineer, USDA-SCS |
| TEXT: | SWCS, Empire Chapter, **New York Guidelines for Urban Erosion and Sediment Control**, October 1991; Soil Conservation Service, Technical Release 55, **Urban Hydrology for Small Watersheds**, June 1986; New York State Department of Environmental Conservation, **Reducing the Impacts of Stormwater Runoff From New Development**, April 1992. |
| GRADING: | Assignments: 40%<br>Mid-Term Exam: 30%<br>Final Exam: 30% |

**Course Content:**

| **Week:** | **Topics:** | **Reading** | **Instructor** |
|---|---|---|---|
| 8/31 | Introduction to Urban Stormwater and Erosion Control Design (1)* | | Lake |
| 9/7 | Resource Planning and Stormwater Impacts (2) | Ch. 1, NY Guide and DEC Manual | Lake |
| 9/14 | Computing and Controlling Sediment and Runoff (2) | Ch. 8, Appendix B, NY Guide | Lake |
| 9/21 | Stabilizing Soil, Vegetative and Biotech (2) | Chs. 4 and 5, NY Guide | Dickerson<br>Lake |
| 9/28 | No lecture—E&S Field Exercise<br>(10/3, 8:30-11:30 AM)<br>(turn in 10/7) | NY Guide | Lake |
| 10/5 | Urban Hydrology (2) | SCS-TR-55 | Lake |
| 10/12 | Urban Hydrology (1) and Site Exercise Critique (1) | | Lake |
| 10/19 | NO CLASS—HYDROLOGY PROJECT | | Lake |
| 10/26 | Urban Hydrology Computer Program (1) and MIDTERM | Tr-55 | Chapman<br>Lake |

**Figure 4. Urban Stormwater and Erosion Control Design course agenda.**

| Week: | Topics: | Reading | Instructor |
|---|---|---|---|
| *Number of lectures that week | | | |
| 11/2 | Construction/Maintenance/Code Enforcement | NY Guide | Proietta |
| 11/9 | Town Planning Board Assignment and Stormwater Field Exercise (11/14—9:00 AM) | | Lake |
| 11/16 | Performance Standards for Stormwater Management | Chs. 5 and 6, DEC Manual | Warrender Morton |
| 11/23 | Flow Routing (1) | | Nix |
| 11/30 | Flow Routing (2) | | Nix |
| 12/7 | Stormwater Basin Design (2) | DEC Manual | Lake |
| 12/14 | Course Review | | Nix |
| 12/21 | FINAL EXAM | | Lake |

## Instructors

Donald W. Lake, Jr., PE, State Conservation Engineer, USDA-SCS

John Dickerson, Northeast Plant Materials Specialist, USDA-SCS

Dana Chapman, Asst. State Conservation Engineer, USDA-SCS

Robin Warrender, Chief, Nonpoint Source, Division of Water, NYS-DEC

William Morton, Resource Specialist, NYS Department of Environmental Conservation

Dr. Stephan Nix, Professor, Syracuse University, Civil and Environmental Departments

**Figure 4. Urban Stormwater and Erosion Control Design course agenda (continued).**

# Field Office Technical Guide:
## *Urban Standards and Specifications*

**Gary N. Parker**
**U.S. Department of Agriculture, Soil Conservation Service**
**Champaign, Illinois**

## Abstract

The *Field Office Technical Guide* is the primary technical reference for the Soil Conservation Service (SCS). It presently contains general resource references and soil and site information, and describes conservation management systems, practice standards and specifications, and conservation effects. Although SCS maintains offices and provides assistance in all Illinois counties, the technical guide does not contain any information specific to natural resource use and management in urban areas. Therefore, in June 1992 the SCS in Illinois entered into an agreement with the Illinois Environmental Protection Agency to develop technical information describing best management practices (BMPs) for controlling urban nonpoint source water pollution.

Currently in development, this information will include 40 BMP standards and accompanying construction specifications, material specifications, and standard drawings. It will also include estimates of pollutant removal effectiveness and stormwater pollutant export, as well as planning and design criteria. When complete, this material will become part of the *Field Office Technical Guide*. The Illinois Environmental Protection Agency will also use the information in a separate, stand-alone technical manual. This material will be useful to planners, engineers, architects, and construction contractors, as well as to local government staff.

## Background

The Soil Conservation Service (SCS), an agency of the U.S. Department of Agriculture, is the major federal agency providing natural resource management assistance on nonfederal land. Its primary responsibility is to provide leadership and expertise in managing natural resources in nonurban areas. Currently, SCS maintains a network of field offices in nearly every county in the country, providing local citizens with direct access to a wide range of technical specialists. These specialists include engineers, soil scientists, biologists, agronomists, and natural resource planners.

The technical material and expertise that has been developed to support SCS activities largely pertains to agricultural or rural settings. For example, the seed mixtures that most SCS specifications call for are those appropriate for agricultural areas and not necessarily for parks, recreation sites, or lawns. In addition, design criteria for waterways and diversions assume an agricultural land use context.

Despite this rural, nonurban emphasis within the agency, SCS maintains a field staff in urban and urbanizing areas. In Illinois, this urban staff serves over one-half the state's population. This urban presence has enabled SCS to develop some urban expertise. For instance, SCS TR-55 hydrology modeling techniques are widely used to estimate runoff from urban areas. Moreover, the PL-566 watershed projects constructed in the Chicago suburbs have given the agency some expertise in urban construction site issues. The SCS, however, has not provided any systematic technical support to its field staff on natural resource management issues in an urban setting. It has instead relied on the ability of its staff to adapt the provided information from a rural to an urban environment.

To become more effective in addressing key natural resource issues in urbanizing areas, the SCS in Illinois has initiated several activities:

- It is actively participating in a coalition of state and federal agencies to prepare a strategy for coordinating agency activities in northeastern Illinois.
- It is reviewing and clarifying its policy relative to providing assistance in nonagricultural areas.

- It is expanding the technical information its staff uses when providing assistance to decision-makers in urban areas.

The third initiative listed is the subject of this paper. In June 1992, SCS entered into an agreement with the Illinois Environmental Protection Agency to prepare a set of standards and specifications describing BMPs for controlling urban nonpoint source water pollution. In addition, the SCS will provide estimates on the range of pollutant removal effectiveness and criteria for planning runoff management. The agency will incorporate all this material into its *Field Office Technical Guide.*

## *Field Office Technical Guide*

The *Field Office Technical Guide* is the primary technical reference for the SCS. It contains technical information about conservation of soil, water, air, plant, and animal resources. The guide is designed for use by technically trained people who are assisting landowners and users, land managers, government officials, and other decision-makers to plan, apply, and maintain appropriate conservation practices. The technical guide also is a major reference for those addressing top-priority resource goals identified by the National Program for Soil and Water Conservation. These goals are to reduce the damage caused by excessive erosion and to protect water from nonpoint source pollutants. The technical guide identifies sediment, nutrients, animal waste, pesticides, and salinity as nonpoint source pollutants.

The *Field Office Technical Guide* contains five sections:

- The "General Resource References" section lists references, cost data, maps, climate data, cultural resources information, threatened and endangered species, and pertinent state/local laws, ordinances, and regulations.
- The "Soil and Site Information" section describes the soil survey of the local area. It contains soil descriptions and interpretations that can be used to make decisions about land use and management. This section identifies soil characteristics that limit or affect land use and management, and rates soils according to limitations, capability, or potential.
- The section on "Conservation Management Systems" provides information for developing resource management systems to prevent or treat problems associated with soil, water, air, and related plant and animal resources. This section includes quality criteria that describe the level of resource protection that decision-makers should try to achieve to meet resource quality goals.
- The "Practice Standards and Specifications" section alphabetically lists conservation practices used by the field office, followed by practice standards and specifications. It may also include references and documentation requirements for the individual practices. Practice standards establish the minimum level of acceptable quality for planning, designing, installing, operating, and maintaining conservation practices. Practice specifications describe the technical details and workmanship required to install the practice, as well as the quality and extent of materials used in the practice.
- The last section, "Conservation Effects," contains information describing the economic and environmental effects of implementing particular practices and systems. The purpose of this section is to provide decision-makers with a way to evaluate the extent to which various alternatives can meet their goals.

As stated previously, this guide is the primary technical reference for SCS staff, particularly those at the field level. The guide is also useful to Soil and Water Conservation District staff, and to consultants and staff of state, county, and municipal governments. To expand its usefulness, however, the SCS urban field staff in Illinois have recommended that the guide include information that is directly relevant to natural resource management in an urban environment and is user friendly to urban clients. The material now being developed will attempt to meet that need.

## New Material for the *Field Office Technical Guide*

The new material will supplement and expand the existing material in the guide's fourth section, *Practice Standards and Specifications*. The SCS will modify or develop 40 BMPs that deal specifically with urban natural resource management.

Each BMP standard will follow a uniform format:

- "Definition": describes what the practice is.
- "Purpose": explains what the intended effect of the practice is, that is, why this practice is used.
- "Conditions Where the Practice Applies": describes the types of sites where the practice would be appropriate; this section also describes limiting factors such as slope percent, maximum drainage areas, and maximum flow velocities.
- "Criteria": describes, in general terms, material and construction requirements and usually provides references to specific material and/or construction specifications.
- "Considerations": offers general information regarding factors to consider when deciding on the appropriateness of a particular practice; in some cases, this section is a brief, narrative, nontechnical summary of the "Conditions" section.

- “Plan and Specification Requirements”: describes the nature and extent of the information the contractor needs to build the practice; it lists the requirements of the plans and specifications needed to install a practice.
- “Operation and Maintenance Requirements”: describes the needed operation and maintenance actions and suggests the frequency with which they should be performed.

The revised fourth section of the technical guide will also include all the material specifications and constructions referenced in the practice standards, as well as a series of standard drawings for the practices. The standards and specifications will be available on computer disk. The standard drawings, which will be developed using a CAD system, also will be available on disk. This will allow engineers and consultants to access the material in preparing construction plans and specifications.

In addition to the SCS incorporating the new material into the Illinois *Field Office Technical Guide*, the Illinois Environmental Protection Agency plans to issue a stand-alone technical manual of those standards for use by consultants, state agencies, and local governments. The project is scheduled for completion in December 1994.

# Stormwater Outreach at the Federal Level: Challenges and Successes

**Kimberly O. Hankins**
**Office of Wastewater Enforcement and Compliance,**
**Office of Water, U.S. Environmental Protection Agency, Washington, DC**

## Background

Stormwater regulations brought a distinctly different community into the realm of U.S. Environmental Protection Agency (EPA) regulation. Many members of this community have never before been regulated by an environmental program. The regulated community now includes all major cities and unincorporated areas with populations of 100,000 or more, as well as a very large, diverse group of industries. The most important factor influencing success with the stormwater regulations is education. By educating all parties concerned with the program, the community can begin to practice all that EPA is learning about how to provide a cleaner, safer environment.

The principal elements of an outreach program are communication and education, with a focus on influencing how people and organizations act. Given this, the National Pollutant Discharge Elimination System (NPDES) stormwater outreach program at the national level should, among other things:

- Disseminate information and educate people about the effects of receiving water pollution from diffuse sources, such as the loss of recreational activities.
- Promote positive environmental results, including the reduction of pollutant loadings into receiving waters.

Theoretically, accomplishing these goals should elicit a successful outreach program at any level. In fact, success is much more elusive. Of course, many outreach programs implement this theory very effectively. At the federal level, however, EPA has 16 different customers reflecting 10 EPA regions, 50 states, thousands of municipalities, and hundreds of thousands of facilities, trade associations, and professional groups. Moreover, when factoring in to this multitude Congress, EPA's own management, and scarce resources, a successful outreach program becomes a tremendously complex and costly endeavor.

At the federal level, it is crucial to provide as much information as possible to as many people as possible. Therein lies the biggest challenge in outreach at the federal level. This paper presents some of the challenges in developing an outreach strategy for the stormwater program at the federal level. It also describes some of the projects EPA's Office of Water has under way, some of which have worked very well and some of which have not. In addition, the paper discusses what the future holds for the stormwater outreach program.

## Challenges of Developing a Stormwater Outreach Strategy

For its first year or so, the strategy of the stormwater outreach program consisted of a hotline, which addressed most needs, and speaking engagements, which filled in the gaps.

Almost immediately after the NPDES stormwater program was born, several years ago, the stormwater hotline was established. Since its inception, the hotline has received over 90,000 calls. The hotline staff answers questions, distributes documents, and handles registration for EPA workshops and seminars.

The other important element of the early stages of the stormwater program was speaking engagements and workshops. These continue to be one of the best ways to get "the word out" correctly. Regulated communities need to know exactly how the stormwater program affects them. For example, the program held 12 workshops between 1990 and 1991 to explain the November 10, 1990, regulations.

As the stormwater program matured, it became apparent that the community needed a more substantial outreach strategy. The hotline staff quickly found it difficult to refer all policy interpretation calls to EPA stormwater staff. At that time, the staff at Headquarters was very small and the regions were overburdened.

Consequently, the Headquarters stormwater staff expanded, and one of its first tasks was to develop an outreach plan. The first step was to identify the plan's customers, which turned out to be just about everyone. Primary customers are the regions and states. Of course, there are 11 categories of regulated industries and over 200 municipalities in Phase I alone. The list of customers continues to grow when the general public, elected officials, professional associations, trade groups, and consultants all are factored in. These groups require a different level of understanding of stormwater regulations. This presented a major challenge because the staff needed to examine each document and ensure that it satisfied the needs of more than one group of customers.

This early outreach strategy assumed knowledge of what the customers wanted. The assumption, however, was wrong. There was one crucial step in strategy development that the stormwater staff neglected to complete: ask the customers. Because of their enormous number, however, asking them all was impossible. Some customers, of course, in addition to the regulated community, are the states and regions, who are trying desperately to run their own stormwater programs. These customers were finally asked about the outreach plan at the 1992 Stormwater Coordinator's Conference in Atlanta, Georgia. The stormwater staff reviewed what they had been doing to date, and customers offered helpful suggestions on what to do next. Customers also participated in a session specifically targeted at designing the stormwater workshops held in April 1993 in Annapolis, Maryland, so as to ensure customer input.

During this meeting, it became apparent that many states and regions were duplicating work unnecessarily, that is, developing something that another state had already developed. This was very frustrating for all those involved. Some kind of clearinghouse or electronic communications system was desperately needed. Research, however, had already shown that it could cost from $750,000 to $1 million to set up such a system. This cost prevented Headquarters from accomplishing this effort on its own. Therefore, it asked the states to help by directing their 104(b)(3) grant funds to this effort. This seemed the only way to accomplish the goal quickly and effectively. Although this sounded like it would work, it has not. There is quite a bit of reluctance to use that money for this task. Therefore, stormwater personnel have begun to look for other avenues.

The challenges multiply when budget constraints are considered. One of the biggest problems involves printing a developed document. The printing budget at Headquarters has taken some very serious cuts. Despite attempts to solve this problem, difficulties continue. For instance, Headquarters has tried to distribute items electronically, but this can cause more problems than it solves. Budget cutbacks have seriously hampered plans to develop more public education materials than are currently available.

Of course, nearly everyone has been hit very hard by budget problems. Some states and counties have offered very creative ideas about getting the "most bang for your buck!" This issue has shed new light on the problem of getting out as much information as possible.

These are just some of the challenges stormwater staff have faced in putting together an outreach strategy. The next section describes some current outreach projects.

## Current and Developing Outreach Activities

### *Research*

A primary task has been to research existing outreach activities. Much information on these activities exists, and both researchers and audiences find this an ongoing educational process. Research efforts include:

- Research on outreach activities
  Audience: Headquarters management, regions
- Research on videos
  Audience: Headquarters management
- Research on clearinghouses
  Audience: Headquarters management, regions

Current research on existing outreach activities examines their successes and failures. Hopefully, this effort will help target materials and practices that can be expanded to a national level. While outreach videos have had difficulty with funding, the staff is researching what is out there, again, in case it finds something that works well and can be expanded to a national level. Finally, research on clearinghouses began before stormwater staff heard from the regions and states. The staff tried to learn of available clearinghouses to examine the possibility of their use or adaptation.

### *Outreach Strategy*

The strategy is expected to be presented in a dynamic document. Its audience is Headquarters management and the regions. Hopefully, the document will provide an adaptable framework for designing and completing outreach projects within an assigned time frame.

### *Fact Sheet Development*

Because the stormwater program involves so many issues and firestorms, staff often produce fact sheets to clear up confusion. Past fact sheets have focused on:

- The Transportation Act's effect on the stormwater program.
- The Ninth Circuit Court decision that affected municipalities.
- The Municipal Part II guidance document.
- Phase II progress and results of public meetings.

### *Question and Answer Document*

The audience for this document is the regions and industries via trade associations. The first volume was developed based on questions from the hotline. The staff compiled over 50 commonly asked questions and answers into one document, which has been distributed through the hotline.

The second volume covers more complex interpretations of the regulations, including questions on sampling, group applications, and the Ninth Circuit Court decisions. Again, distribution will probably proceed through the hotline.

### *Stormwater Workshops*

In fiscal year (FY) 1991, the stormwater staff at Headquarters conducted 12 workshops on the basics of the stormwater program. The workshop audience consisted of regions, states, and the regulated community. The objective was to inform as many people as possible about the requirements of the November 16, 1990, rule. Attendance was in the thousands. The effort was successful.

In FY 1992, the stormwater staff presented workshops and spoke to over 4,000 people. These workshops focused on the requirements of the general permit and the development of pollution prevention plans. In addition, workshops for municipalities covered the requirements of the Part 2 municipal application. All these workshops were well received and also considered successful.

The FY 1993 workshops presented by Headquarters focused on developing pollution prevention plans. The staff developed a workshop series with the first day targeted to reach state and EPA regional representatives. This day is a train-the-trainer session to teach the audience how to lead a workshop on pollution prevention for industry. The second day is designed for the industrial regulated community and focuses on industrial and construction pollution prevention plan development. This day should include case studies and interactive exercises.

These workshops mark the first effort by the stormwater program to conduct workshops of this kind. The hope was to meet the objectives identified by the regions and states at the 1992 Stormwater Coordinator's Conference in Atlanta. Due to budget problems, Headquarters was limited to the number of workshops it could conduct in each region. The goal was, however, for state and regional staff to be able to present the workshops on their own. Each state was to receive a set of slides and speaking materials for its own use.

### *Municipal Support Division/Permits Division Pamphlet on Stormwater*

The audience for this publication is Headquarters, the regions, and the general public. This project has experienced difficulties getting started due to contractual problems. It is, however, now moving ahead toward completion. The pamphlet is predominantly aimed at members of the general public who have little or no knowledge of the stormwater program.

### *Updated Stormwater Overview*

This document addresses general information needs. Its audience consists of Headquarters, the regions, and the general public. The Overview reviews who the stormwater program covers, what their application options are, and what the deadlines are associated with those applications. As the program grows and changes, the Overview is updated. Distribution is currently through the stormwater hotline.

### *Raindrop Report (Status of the Stormwater Program)*

This document is targeted to Headquarters, the regions, and the general public. It supplies a brief update on current activities in the stormwater program and features relevant information from recent *Federal Registers.* In addition, it describes outreach activities and provides specifics on applications submitted and general permits.

### *Articles for Newsletters*

Stormwater staff are developing articles by request for publication in various journals and newsletters. They are trying to establish a regular submittal effort to some publications, such as the *Nonpoint Source News Notes,* which is published by the Headquarters nonpoint source program to supplement the bulletin board.

### *General Permit Effectiveness Study*

The purpose of this effort is to determine the effectiveness of the general permit approach in implementing Phase I. The evaluation assesses, among other things, the rate of compliance, the level of awareness, and the quality of pollution prevention plans being developed. This effort also is identifying obstacles that prohibit the general permit from being as effective as possible.

### *Monthly Conference Calls*

As of March 1993, Headquarters had completed 15 regularly scheduled conference calls with stormwater regional coordinators. These meetings have proven very successful, and they should continue.

### *Stormwater Awards*

These awards recognize municipalities and industries that demonstrate a commitment to protecting and improving the quality of the nation's waters through outstanding implementation of innovative and cost-effective stormwater control programs and projects. In 1991, the winner for a stormwater control program or project by a municipality was Murray City, Utah. In 1992, the city of Orlando, Florida, won, and Prince George's County, Maryland, took second place. Nominations are sought from the 10 EPA regions.

### *National Stormwater Coordinator's Conference*

This annual event is indispensable for planning and feedback from the states and regions. The meeting is designed for regional and state stormwater coordinators, as well as for Headquarters staff.

### *Continuous Speaking Engagements*

Stormwater staff receive requests to speak to groups twice a week on average. While they are not always able to fill some requests because of a limited travel budget, the staff respond to as many as possible. In FY 1992, staff participated in about two dozen talks or seminars, not including the workshops.

### *Phase II Outreach Meetings*

The Phase II Outreach Meetings are a series of meetings designed to include individuals that may be affected by the Phase II regulations in the development of those regulations. As of this writing, four meetings have been held (two in Washington, one in Dallas, and one in Chicago) to involve as many people as possible.

### *Information and Education Catalog*

Another important project is the management and periodic update of the Information and Education Catalog, which was distributed at the National Urban Runoff Management Conference. The author and Tom Davenport manage this project. Everyone concerned should have a copy of this excellent document. Management plans to expand the manual to include stormwater information. In addition to putting out several calls for information, the conference registration packet included a form to fill out if individuals wanted this catalog to include a particular document. Management believes this document will help in the tremendous demand for technology transfer in the stormwater and nonpoint source programs. This, of course, is a top priority that customers have requested.

### *Electronic Sources*

Linking to other clearinghouses and bulletin boards should improve communications. The nonpoint source program at Headquarters has been extremely helpful by placing information and announcements on its electronic bulletin board and in the *Nonpoint Source News Notes* publication. This has proven to be a good way to meet customer needs.

## Further Considerations

Education is becoming one of the most important aspects of the stormwater program as people learn about the regulation and how it affects their day-to-day lives. Industries as part of their pollution prevention plans are developing training and education programs for their own employees. Cities are training their employees in sampling techniques and safety procedures as well as developing excellent public education programs. Tremendous efforts involving stormwater education are being undertaken. Stormwater Headquarters needs to know about the successful programs to help the lesser programs learn.

As this program moves forward, each success in educating those affected by the stormwater program, including the general public, leads to greater accomplishments. As these successes continue to build, more people will understand the intent and effects of protecting and cleaning up the waters of our nation. It is a cycle in which we all play a major role.

# *Training for Construction Site Erosion Control and Stormwater Facility Inspection*

**Richard Horner**
**University of Washington, Seattle, Washington**

## Abstract

Probably the leading reason that stormwater management programs fail in effectively protecting water resources is the lack of followup to ensure that permit conditions are met, approved designs are properly installed, and temporary and permanent management practices and facilities are maintained. Avoiding this downfall requires obtaining the legal authority for and then instituting a coordinated program extending from the first submission of permit applications through construction and all phases of site operation. This program should have components covering the construction phase as well as permanent practices and facilities. While somewhat different elements are appropriate for the two components, they share the common precepts of sound underlying planning; competent plan review; and effective inspection, maintenance, and enforcement. The University of Washington's Center for Urban Water Resources Management and Office of Engineering Continuing Education have developed and are offering courses to train personnel responsible for various aspects of the suggested program. This paper emphasizes the training for site inspectors. For construction-site inspectors, it covers the role of the erosion and sediment control (ESC) plan, the applicability of many ESC practices, key points to check when inspecting them, and how to deal with various circumstances that can arise during inspections. For permanent drainage system inspectors, the paper covers both the initial construction and continuing operation of facilities and offers guidance on key inspection points and such issues as safety, tracking maintenance, and waste handling.

## Introduction

Effective stormwater management requires successful execution of steps at all phases of a project. These phases and the accompanying management steps include analysis of potential problems in the planning stage, quality design of programs and practices to protect aquatic resources as the project takes shape, competent review of plans at the permit application point, proper implementation of approved plans during construction, and correct operation and practices at facilities after their installation. All phases of the process need improvement through a better basis in knowledge and greater skills in application. Probably the weakest areas and the leading causes of program failures and environmental damage are implementation during construction and long-term operations.

Redressing this weakness will require widespread development of comprehensive and aggressive programs of inspection during the construction of developments and their stormwater management systems, followed by ongoing inspection of operating systems to ensure sufficient maintenance for continuing adequate performance. The diffusion of development and tradition of local land-use control prevalent in most of the United States will necessitate local acquisition of the legal authority, where it does not now exist, to institute these programs. As is already occurring in some places, it is likely that larger units of government will become involved in setting standards for these programs. The U.S. Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) program is presently extending authority over programs in the largest cities and counties and at sites of construction larger than 5 acres and involving industrial activity. Still, the details and the responsibility for conducting the programs will very likely rest with local governments.

The concern of this discussion is the development and execution of local programs to upgrade significantly the quality of followup to increase the probability that approved stormwater management plans are effective. The scope of the programs envisioned would extend from the point of permit issuance through construction and all the years of site operation to follow project completion. The programs might be considered to have distinct components, covering, for example, erosion and sediment control (ESC) inspection at construction sites, inspection of the construction of storm runoff quantity and quality control facilities, and the periodic inspection and maintenance of operating facilities. However they are structured, these programs should embrace some common principles. They should be the logical extension of and ultimate implementation vehicle for the foregoing phases of planning, design, and plan review. Further, they should be conceived and conducted as essential elements of a successful program, deserving of the needed funding, staffing, support by administrators and public officials, training of personnel, and enforcement authority.

This discussion covers aspects of program development and especially emphasizes training for site inspectors. For these purposes it divides the overall program into two components. One covers construction site ESC programs. The second covers permanent drainage practices and facilities, both their inspection at construction and followup inspection and maintenance. In both cases, the paper recommends program structures and discusses some key program elements. It then offers specific examples of inspection checks to perform in the field. The goal of the paper is to give the reader a basis for beginning program design and undertaking the key element of training the staff who will be charged with its performance.

The discussion was derived from two courses developed and offered by the University of Washington's Center for Urban Water Resources Management and Office of Engineering Continuing Education. The course coverage is organized in the same manner as this presentation, and course manuals are available for ESC inspector training (1) and permanent drainage system inspector training (2). Important contributions to the material presented in these courses and in this discussion have been made by local governments and state agencies in the Puget Sound area of Washington state that have been working actively to improve stormwater management through good followup.

## Construction Site ESC Inspection Programs

### *Program Development*

#### Program Elements

The following elements are recommended for a comprehensive construction site ESC program:

- ESC planning
- A plan review process
- Contractor education
- An inspection and enforcement process

The subsections to follow cover two of these program elements in detail, ESC planning and inspection and enforcement. The latter discussion is then extended in the following section to examples of inspection guidelines for common practices.

#### ESC Planning

ESC planning is an absolute prerequisite for an effective program. A careful site analysis should produce a stand-alone plan (i.e., a plan devoted exclusively to this aspect of the project) developed with the same thoroughness and care as any other plan in the overall construction set. It is intended for use by the plan reviewer, the construction superintendent and other contractor personnel, and the construction site inspector. This subsection outlines the ESC planning process from beginning to end and concludes with an example of a complete plan.

In approaching an ESC plan, the planner must:

- Understand the erosion process, so that it can be controlled.
- Know the site and the construction plan, so that both potential problems and solutions will be apparent.
- Understand the various ways that erosion can be prevented or that eroded sediments can be caught.

The erosion process is first reviewed for the lessons it can offer ESC planning. Erosion has been understood for thousands of years, as is attested by the extensive evidence of terraced farming—some continuing today—in steep terrain in ancient cultures. Figure 1 illustrates the types of erosion and its nature. Soils can be loosened and set in motion initially by the impact of falling raindrops. Erosion progresses, although gradually, as runoff flows in a sheet over a bare surface and exerts shear stress, which is a function of velocity, on soil particles. The rate of erosion increases when flow concentrates and increases in velocity. Channels formed by these flows are known as rills. When rills join and form highly concentrated, rapidly flowing channels, the rate increases still further, a stage termed gully erosion. Erosion can progress still further to mass wasting when a whole area loses stability.

Several factors involving site soils, vegetation, and topography influence the erosion process. Soil erodability is greater in the case of silts and fine sands than clays or soils with a substantial gravel content. Relatively high organic content also offers cohesiveness that resists erosion. Clays tend to produce a larger volume of runoff, however, because of their relatively poor permeability, which exerts more erosive stress on soil. Vegetative cover offers a number of important advantages, including reducing raindrop impact, slowing runoff velocity, helping to absorb water, and holding soil in place. In regard to topography, both slope gradient and length tend to increase velocity and the resulting frictional

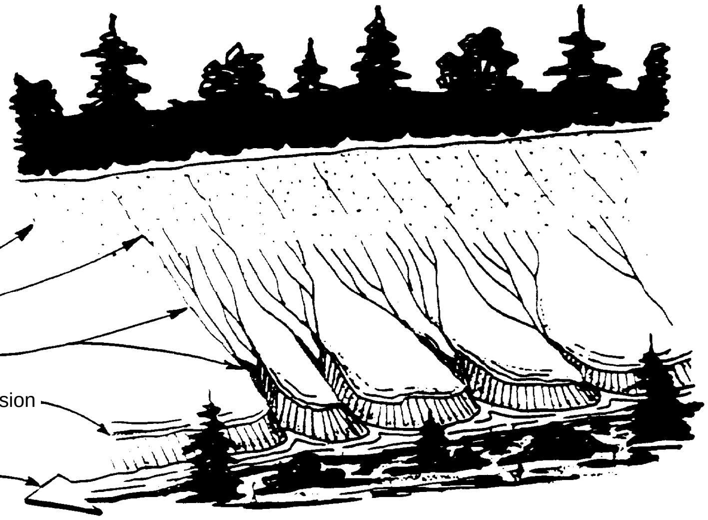


**Figure 1. Soil erosion processes (3).**

shear stress. Erosion hazards relative to slope gradient and length are listed in Table 1.

Acquiring the familiarity with the site and proposed construction necessary to proceed with the ESC plan involves data collection and analysis. Site data should be collected in regard to:

- Soils
- Vegetation
- Topography
- Ground-water table
- Neighboring water bodies
- Adjacent properties
- Drainage routes and patterns (define subbasins)
- Potential areas of serious erosion problems
- Existing development, utilities, and dump sites

The following construction plan information should be cataloged at the outset of planning:

- Grading (location, amount)
- Topographic changes
- Clearing and grading limits
- Drainage changes

**Table 1. Soil Erodability Relative to Slope Gradient and Length**

| Erosion Hazard | Slope Gradient | Maximum Length |
|---|---|---|
| Low | 0-7% | 300 ft |
| Moderate | 7-15% | 150 ft |
| High | >15% | 75 ft |

- Materials to be used and locations of use and storage
- Access points

ESC planning should proceed with reference to certain basic principles, as follows:

- First consider all means of preventing erosion; only consider trapping sediments from unavoidable erosion. Prevention has the potential to be more effective in resource protection than later treatment and less costly.
- Phase construction and post clearing limits to maintain as much natural vegetation as possible and for as long as possible.
- Plan construction to fit the site; use terrain advantageously and avoid critical areas.
- Cluster buildings and other developed features, and minimize their impact on impervious area.
- Plan for control of erosion subbasin by subbasin.
- Minimize extent and duration of vegetation removal (especially during wet season) and soil disturbance.
- Stabilize and protect disturbed areas as soon as possible.
- Use natural drainage features, existing vegetation, and materials found on the site.
- Minimize slope length and gradient to control runoff velocities.
- Divert offsite runoff away from disturbed areas.
- Retain any released sediment within the construction area and reduce tracking off site.
- Have a thorough maintenance and followup program.
- Take measures to control potential pollution from construction materials (e.g., paving materials, petroleum

products, other vehicle fluids, fertilizers, pesticides, grinding and sanding debris, wastes).

An ESC plan consists of a narrative and site plans. Points that should be covered by the narrative include 1) a project description, 2) a description of existing and modified site conditions, 3) descriptions of ESC best management practices (BMPs), 4) descriptions of BMPs for pollutants other than sediments, 5) plans for permanent stabilization, 6) calculations, and 7) provisions for inspection and maintenance. Site plans are maps and engineering plans illustrating and specifying the project's location, existing and modified site conditions, and BMPs. The set of site plans should include 1) a data collection worksheet (principally showing topography, soils, and vegetation), 2) a data analysis worksheet (mainly indicating drainage subbasins and primary drainage courses), 3) a site plan development worksheet (showing existing and finished contours, roadways, and permanent stormwater facilities), 4) the ESC plan (showing BMP locations), and 5) diagrams of representative BMPs, as appropriate. The ESC plan (item 4 in the set) is the key element for implementing the plan. BMPs are usually specified on this plan using a system of symbols, which are defined in a legend.

### Inspection and Enforcement

The most important general needs of an inspection and enforcement program are a staff dedicated to the function, specific staff training, and administrative support. These needs are best provided for by a dedicated revenue source, such as a stormwater utility assessment. The staff should not have unrelated and distracting duties such as inspection of other facets of construction. Initial training should offer needed background in, for instance, legal and regulatory requirements, water quality, hydrology, soils, and vegetation. Subsequent training should provide detailed coverage of BMP requirements, such as discussed in the following section. Strong support from administrators is essential for a staff undertaking a relatively new function that might be unpopular in terms of economic interests.

Beyond these basic needs are some specific issues to clarify during program development for incorporation as formal program elements. Recommendations on the issues presented in this paper are drawn from experience in the Puget Sound region, especially in King County and the cities of Bellevue and Redmond. One of these issues is the response to a situation in which measures in an approved ESC plan proved inadequate. Strong permit review should normally limit these instances, but unforeseen circumstances can still arise. Inflexible adherence to an ESC plan can be self-defeating when measures prove to be inadequate for whatever reason; thus, the jurisdiction should retain the authority to require additional measures if needed. This option should be noted in a statement on each ESC plan.

A second issue is how field change orders will be handled. The policy should call for careful but expeditious consideration of requests for plan changes, generally after consultation with plan review personnel. Finally at issue is the granting of variances from code requirements. Conditions on granting variances should be strict and specific, such as:

- The expected result should be at least comparable to the outcome expected to be achieved with the approved method.
- Sufficient background information and justification should be presented for adequate assessment of the alternative.
- The ability should be retained with the variance to meet objectives of safety, function, appearance, environmental protection, and maintainability based on sound engineering judgment.
- The variance should be in the public interest.

Enforcement authority must be obtained and the system of enforcement defined and made clear to the regulated parties. A system successfully used by the city of Bellevue has a sequence of three steps, as follows:

- A verbal warning, with a deadline for correction.
- A correction notice (with specifications of corrections), a deadline, and a warning about the consequences of noncompliance.
- A stop-work order, with a warning about the consequences of noncompliance.

## *ESC Practices and Their Inspection*

### Categories of Practices

The numerous ESC practices in use can be categorized in various ways. The most basic division is between erosion control practices, which prevent or minimize erosion, and sediment control practices, which attempt to capture soil released through erosion. Within each of these broad groupings are several categories that represent general strategies for achieving either erosion control or sediment control. In addition to sediments, construction sites can generate many other pollutants, such as petroleum products, solvents, paints, sanding dusts, pesticides, and fertilizers. It is most efficient to manage those materials along with sediments and to inspect the management practices for them simultaneously with ESC inspection. Therefore, these practices represent another basic division.

Following is the breakdown of ESC practices used by Reinelt (1), with the number of individual practices in each category. The 29 practices represented are by no means the only ones, but they are the most widely recognized and used. Twenty-two of the 29 (all but the sediment trapping techniques) are preventive and are thus generally the most cost-effective options; however, the straw bale and filter fabric fences and sedimentation ponds among the trapping techniques are most commonly used practices.

1. Erosion control
   - 1.1. Natural vegetative cover—two practices
   - 1.2. Temporary cover—three practices
   - 1.3. Permanent vegetation establishment—two practices
   - 1.4. Stabilized construction entrance and roads—three practices
   - 1.5. Runoff control—eight practices
2. Sediment trapping techniques—seven practices
3. Management of other construction site pollutants—four practices

The following passages provide inspection checklists for example practices, generally the most common, in each category and subcategory. The checklists are divided into checks to be made when the practice is implemented and checks to be made on each followup visit to determine the need for maintenance or replacement of the ESC materials. Many of the points are illustrated in diagrams that accompany the checklists.

While much of an inspector's work is performed in the field, it is often advisable or even absolutely necessary to do some background work in the office before going out to inspect an installation. This work mainly consists of consulting the ESC plan to determine the specifications. The plan should be retained on the construction site should the inspector or construction personnel need to refer to it.

1. Erosion control

1.1. Natural vegetative cover

1.1.1. Phasing construction

Phasing construction is a practice in which clearing operations are performed in stages to take advantage of cover that exists on site before construction.

Installation checks:

1. Are areas that will not be cleared set off with plainly visible clearing-limit fencing?
2. Is plainly visible flagging placed at the drip line of trees to be protected (see Figure 2)?
3. Are fills and cuts near protected trees treated as shown in Figure 2?
4. Is final vegetation established as soon as portions of the site can be made ready?

Maintenance checks:

1. Do fencing and flagging need repair or replacement for personnel to see it clearly?
2. Do exposed or injured roots of protected trees need covering or dressing?

1.2. Temporary cover

Temporary cover practices recognize that portions of most construction sites remain unworked for months, during which time very large amounts of erosion can occur unless these areas are stabilized. Stabilization can be achieved with temporary seeding or various kinds of slope coverings, or both. Slope coverings include both mulches and commercial mats and blankets. It is often necessary to apply temporary cover to different areas several times during construction.

Mulches, mats, and blankets can serve several purposes in erosion control: covering the slope temporarily to prevent erosion by raindrop impact and the friction of runoff, holding water to encourage grass growth, protecting grass seedlings from heat, and enriching the soil. Straw, hay, wood fiber, wood chips, and other natural organic materials can serve as mulches. Inspection guidelines for straw and wood fiber are given below as examples. Mats and blankets are manufactured from both natural and synthetic materials. Guidelines are given for several varieties.

1.2.1. Temporary seeding

Installation checks:

1. Is the soil stabilized within the period specified by regulation? (This period varies from place to place, depending on climate patterns. In the Puget Sound area of Washington, which receives most of its rainfall in the winter, the specified periods are within 2

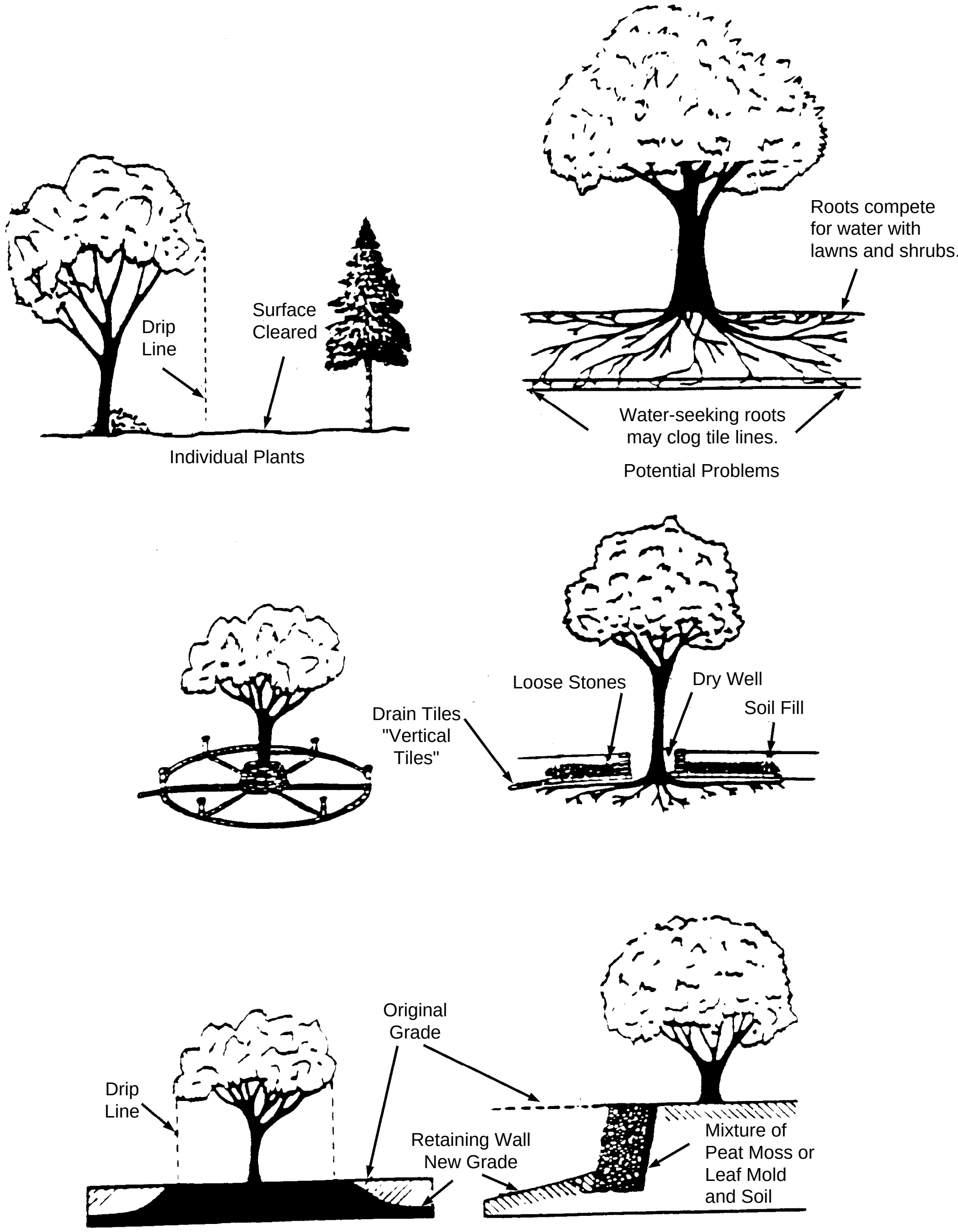


**Figure 2. Guidelines for preserving natural vegetation (3).**

days during the months October to April and within 7 days during the months May to September.)

2. If used without slope covering practices, is temporary seeding limited to slopes of less than 10 percent and 100 ft in length? If the slope exceeds either limit, is a mulch or mat slope covering used?

3. Has the seedbed been prepared with at least 2 to 4 in. of tilled topsoil?

4. Is fertilizer use limited as much as possible; if used, is it applied in amounts no greater than the needs of the grass for the prevailing soil conditions?

5. Is mulch applied for protection if seeding occurs when temperatures can be high or runoff is likely to occur before the grass is well established?

6. Is irrigation provided if planted when rainfall might be insufficient for good establishment?

Maintenance checks:

1. Is it necessary to irrigate and/or reseed?

2. Is maintenance fertilizer needed?

1.2.2. Straw mulch

Straw mulch can be used without seeding or, for better erosion control, with seeding.

Installation checks:

1. Is the straw spread generally a minimum of 2 in. deep (corresponds to 2 to 3 tons per acre) and greater on very steep slopes, adjacent to sensitive areas, and where concentrated flow passes over the slope?

2. Is the mulch anchored as needed by crimping, disking, rolling, or punching into soil or by moistening, tackifying, or netting?

Maintenance checks:

1. Is replacement needed as a result of blowing away or decomposition over time?

2. Is there any fire hazard requiring moistening?

1.2.3. Wood fiber mulch

Wood fiber mulch should only be used with seeding and generally should be used with a soil bonding agent.

Installation checks:

1. Is the mulch used with seeding and a soil bonding agent? Were the bonding agent distributor's application guidelines followed?

2. Has the wood fiber been applied to cover the soil completely, allowing no bare soil to show through (corresponds to about 1 ton per acre and is adequate for most circumstances)? Are there any special circumstances, such as seeding during hot weather, when the amount should be increased by about 50 percent?

Maintenance checks:

1. Is replacement needed as a result of loss over time?

1.2.4. Excelsior

Excelsior is a product made of fine wood shavings that assume a more-or-less helical form. As a consequence of this form, excelsior does not lie in close contact with the soil and allows runoff to drain beneath it and cause erosion. Therefore, it should be used only with seeding, where it is very useful in holding moisture and providing protection from direct sun in hot periods. Suppliers generally market several grades for sheet and channelized flow and different velocities.

Installation checks:

1. Is the excelsior used only with seeding?

2. Was an appropriate material selected according to manufacturer's recommendations and then placed and stapled as recommended by the manufacturer?

3. On slopes, was it placed 3 ft over the crest or in an anchor ditch?

4. In ditches, was it placed in the direction of water flow with any seams offset 6 in. from the ditch centerline?

Maintenance checks:

1. Is replacement needed as a result of damage or loss over time?

1.2.5. Mats and blankets

Examples of materials produced in a mat or blanket form for erosion control are jute, woven straw, and synthetics. Mats can be used without seeding, or with seeding for better erosion control. As with excelsior, suppliers generally market several grades for sheet and channelized flow and different velocities.

Installation checks:

1. Was an appropriate material selected according to manufacturer's recommendations and then placed and stapled as recommended by the manufacturer?
2. Was it placed in the direction of water flow, in full contact with the soil but not tightly stretched?

Maintenance checks:

1. Is replacement needed as a result of damage or loss over time?

1.3. Permanent vegetation establishment

Permanent vegetation should be established as soon as possible after all construction is completed in each segment of the site. Grass can be established by seeding or sodding. Seeding is generally preferred because of the lower cost and greater flexibility in selecting grass species. Sod is often available only in limited varieties, which may not be the most suitable for erosion control and other purposes unless grown to order. In some cases, overseeding with preferred species is recommended in the spring, when grass must be established with sod in the winter. Species should be selected based on local climatological and soil conditions, with reference to regional guidance documents, and, when necessary, in consultation with regional experts.

1.3.1. Permanent seeding

Installation checks:

1. Has the seedbed been prepared by loosening with a plow if subsoils are highly compacted, spreading 2 to 6 in. of topsoil, and lightly rolling?
2. Is fertilizer use limited as much as possible; if used, is it applied in amounts no greater than the needs of the grass for the prevailing soil conditions?
3. Is mulch applied for protection if seeding occurs when temperatures can be high or runoff is likely to occur before the grass is well established?
4. Is irrigation provided if planted when rainfall might be insufficient for good establishment?

Maintenance checks:

1. Is it nencessary to water, reseed, or add fertilizer?

1.3.2. Sodding

Installation checks:

1. Is the sod placed from the lowest area and perpendicular to water flow?
2. Are sod strips wedged tightly together and joints staggered at least 12 in.?
3. Is the sod stapled if on a steep slope?

Maintenance checks:

1. Is overseeding needed, either to repair damage or to install a preferred grass species?

1.4. Stabilized construction entrance and roads

The entrance is the most important access route to stabilize, since it is the last point at which tracking sediment off site can be stopped. If equipment travels extensively on unstabilized roads on the site, a tire and vehicle undercarriage wash near the entrance will be needed. Perform washing on crushed rock. Wash water will require treatment in a sediment pond or trap.

1.4.1. Stabilized construction entrance (see Figure 3)

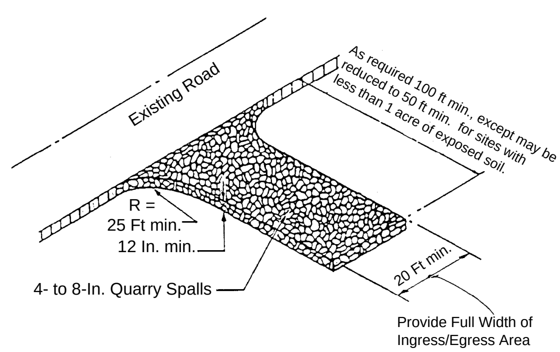


**Figure 3. Stabilized construction entrance (from Washington Department of Ecology, 1992).**

Installation checks:

1. Is the entrance constructed with quarry spalls 4 to 8 in. in size and at least 12 in. thick?
2. Is the stabilized entrance sized correctly for the site?
3. If the entrance sits on a slope, is a filter fabric fence in place downgradient?

Maintenance checks:

1. Is the entrance clogged with sediments, requiring top dressing the pad with clean 2-in. rock?
2. Is it necessary to clean up any sediments carried from the site onto the street?

1.5. Runoff control

Runoff control represents various practices designed to keep water from coming in contact with bare soil or controlling its velocity if it does. Included are drains for surface and subsurface water, dikes and swales placed across slopes to interrupt runoff, and roughness created on the surface to reduce velocity. Example guidelines presented below are for a pipe slope drain and surface roughening.

1.5.1. Pipe slope drain (see Figure 4)

A temporary pipe slope drain is an effective technique for preventing erosion on a slope caused by runoff from a higher elevation. Upslope runoff needs to be collected and directed into the drain effectively and then discharged in a controlled way to prevent erosion at the bottom of the slope.

Installation checks:

1. Are no more than 10 acres drained into a single pipe slope drain?
2. Was a minimum 6-in. metal toe plate placed at the entrance to prevent undercutting?
3. Is runoff directed into the pipe with interceptor dikes at least 1 ft higher at all points than the top of the pipe?
4. Is there a slope toward the pipe on a grade of at least 3 percent at the inlet?
5. If the pipe is 12 in. in diameter or larger, was a flared entrance section installed and connected securely to the drain with water-tight connecting bands?

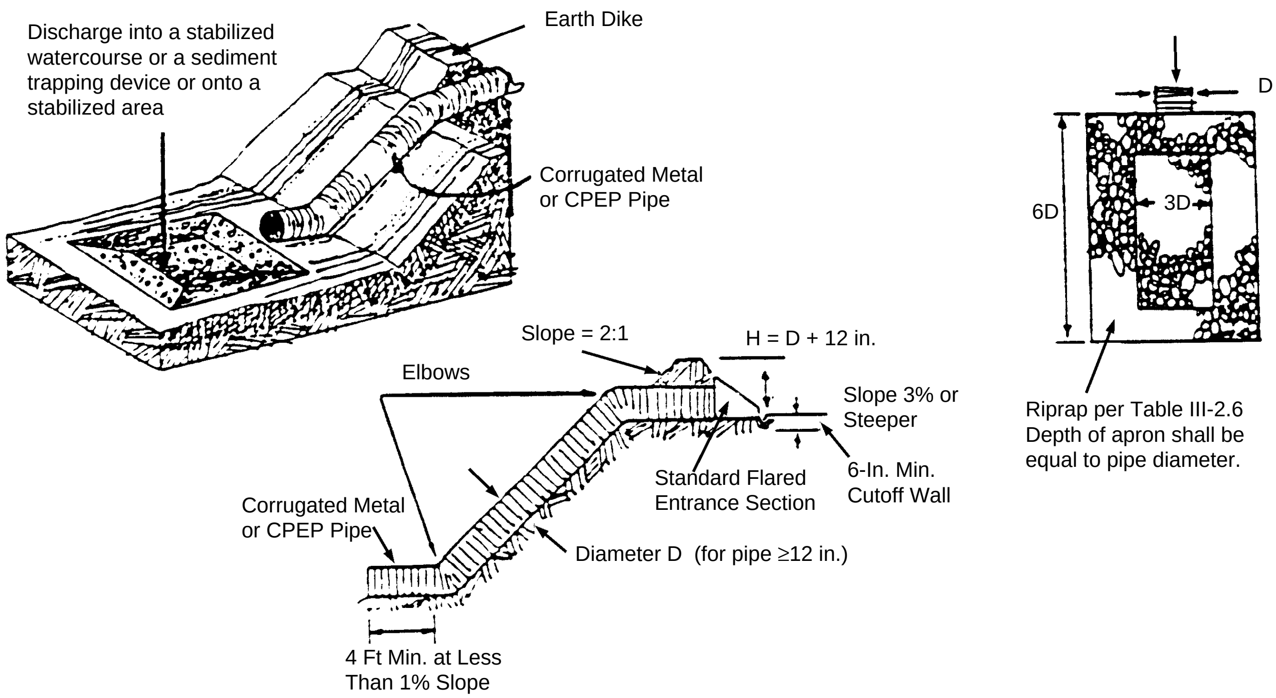


**Figure 4. Pipe slope drain details (3).**

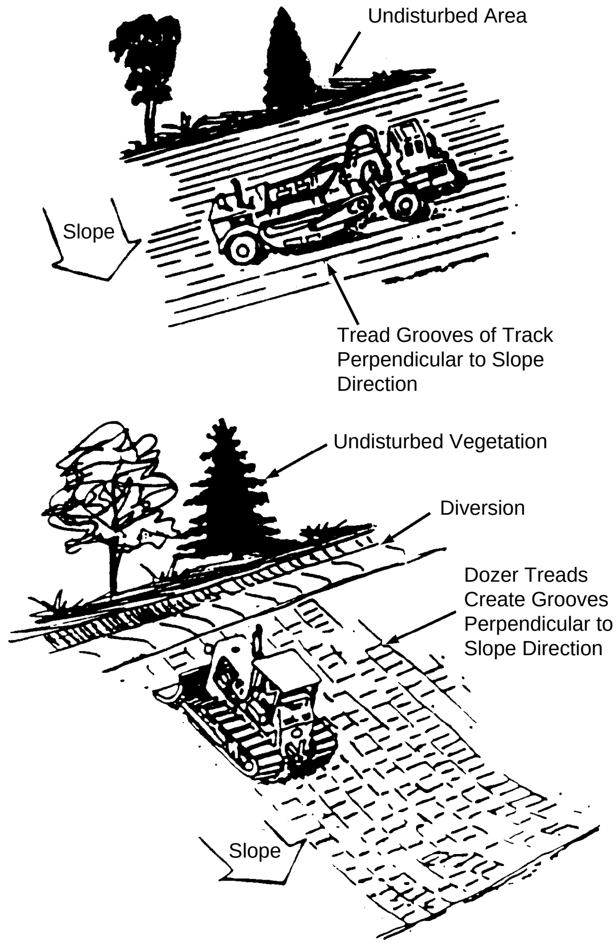


**Figure 5. Examples of surface roughening using heavy equipment (3).**

6. Was the soil thoroughly compacted at the entrance and underneath the pipe?

7. Were gasketed, water-tight fittings placed between pipe sections, were the sections securely fastened, and was the drain anchored to the soil?

8. Was the area below the outlet stabilized with a riprap apron?

9. If the drainage can carry sediment, is it treated in a sediment pond or trap?

Maintenance checks:

1. Is undercutting or bypassing occurring at the inlet, requiring reinforcing of the headwall with compacted earth or sandbags?

2. Is erosion occurring at the outlet, necessitating rebuilding the apron?

1.5.2. Surface roughening (see Figure 5)

A roughened surface is an easy and inexpensive way to reduce runoff velocity, encourage the growth of vegetation, increase runoff infiltration, and trap some sediment. It is not effective enough to use alone but can reduce the load on sediment trapping installations downstream. Roughening is best used on slopes steeper than 3 horizontal to 1 vertical that do not require mowing. There are several methods of roughening a surface, all of which involve forming horizontal depressions with equipment. Methods include tracking perpendicular to the slope direction, driving treaded equipment along the slope direction to get grooves perpendicular to the slope, or tilling (preferred because it avoids compaction). On steeper slopes (steeper than 2 horizontal to 1 vertical) a stair-step pattern should be formed.

Installation checks:

1. Have all exposed slopes steeper than 3 horizontal to 1 vertical been roughened, with 40- to 50-in. stair-step patterns formed on slopes steeper than 2 horizontal to 1 vertical?

2. Was the soil scarified if it was heavily compacted by the roughening?

3. Was the area seeded as quickly as possible?

Maintenance checks:

1. Have rills appeared that should be regraded and reseeded?

2. Sediment trapping techniques

Trapping sediments once they are released requires slowing the transport velocity sufficiently for soil particles to settle (i.e., reducing the velocity below the settling velocity of the particles). Soil particles range over several orders of magnitude in size, from the small clays to the large sands. Settling velocity is approximately related to the square of the particle diameter; thus, halving the diameter approximately quadruples the time needed for settlement. Therefore, as particles decrease in size, they become increasingly difficult to remove from a runoff stream. This fact is largely why preventive techniques are more cost effective than sediment trapping practices and are strongly preferred.

The two basic types of sediment trapping techniques in use are sediment barriers and settling ponds. Sediment barriers include the commonly used filter fabric and straw bale fences as well as brush fences and barriers constructed of gravel. Both types trap sediments in the same way, by ponding water. Although that mechanism is more obvious in the case of ponds than of barriers, practices of the latter type actually provide only a minimum of filtering capability and primarily slow the flow of water long enough for some particles to settle. Thus, they can only trap relatively large particles, generally the larger silts and sands. The trapping ability of settling ponds depends on their size. While they can theoretically be made large enough to trap any size particle, practical sizes generally limit efficient removal to the medium silts and larger.

2.1. Sediment barriers

Several principles apply to the various types of sediment barriers. Maximizing a sediment barrier's ponding volume maximizes the amount of sediment trapped. Therefore, the barriers should be placed away from the immediate toe of slopes in order to increase the area for ponding. It is very important that sediment barriers be aligned on the contour, not up and down slopes. This alignment places them at a right angle to flow paths and also increases ponding volume. Slopes draining to sediment barriers generally should not be more than 100 ft long. Sediment barriers must be trenched in and staked to hold up under the pressure of the wall of water they will dam. Finally, sediment barriers do not provide effective sediment removal from concentrated flows. While straw bales are sometimes used in ditches, rock check dams are really a better alternative for decreasing velocity in channels.

2.1.1. Filter fabric fence (see Figure 6)

Installation checks:

1. Are filter fabric fences used only in the following applications:

   Maximum of 1 acre served by a single fence?

   Maximum 1:1 slope gradient and 100-ft slope length?

   Sheet flow situation (never in concentrated flow)?

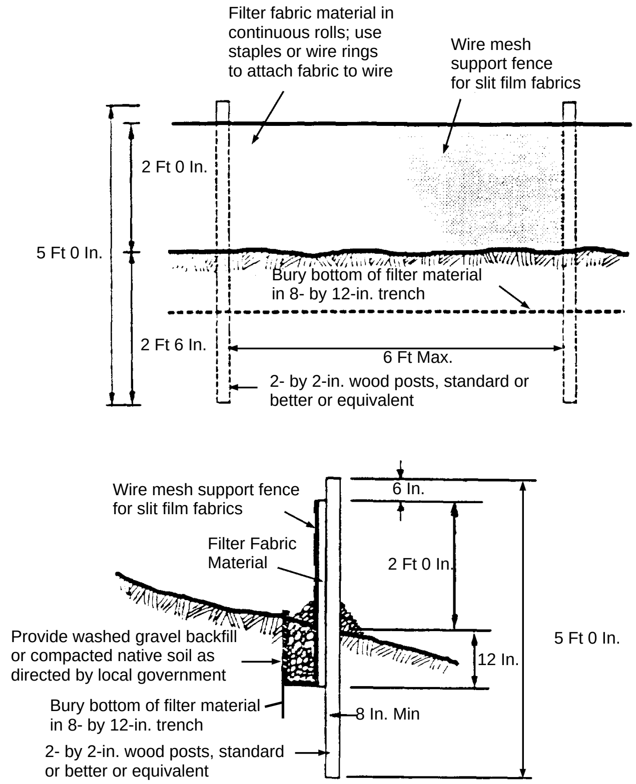


**Figure 6. Filter fabric fence detail (3).**

2. Is the fence aligned to slope contours as well as possible?

3. Is the fence installed so that its height above the soil is no more than 3 ft?

4. Are posts 2 x 4 in. wood or 1.33 lb/ft steel, or the equivalent?

5. Are posts buried 2.5 ft deep whenever possible and spaced no more than 6 ft apart?

6. Is fabric attached on the upslope side with staples (at least 1 in.), tie wires, or hog rings?

7. Is the end of the fabric buried in a trench sized as shown in Figure 6 and backfilled on both the upslope and downslope sides (as shown)?

8. Is splicing avoided if possible? If impossible, is splicing done only at posts and overlapped at least 6 in.?

9. Nonwoven and woven monofilament materials have the best properties for silt fencing. If a woven slit-film fabric is used, is wire mesh reinforcing (14-gauge rein-

forcing wire mesh with openings no larger than 6 in.) placed on the upslope side and fastened the same as the fabric?

Maintenance checks:

1. Is it necessary to restake, reattach, or replace the fence to maintain all of the above conditions?

2. Is sediment removal needed (before it reaches 1/3 the height of the fence)?

2.1.2. Straw bale fence (see Figure 7)

Straw bale fences tend to swell when they get wet and require frequent maintenance. They are not highly recommended but could be more effective if used according to the following guidelines.

Installation checks:

1. Are straw bale fences used only in the following applications:

   Maximum of 1/4 acre served per 100 ft of fence length?

   Maximum 2:1 slope gradient and 100-ft slope length?

2. Is the fence aligned to slope contours as well as possible?

3. Are the bales bound with wire, preferably, or string placed around the sides of the bale, parallel to the ground?

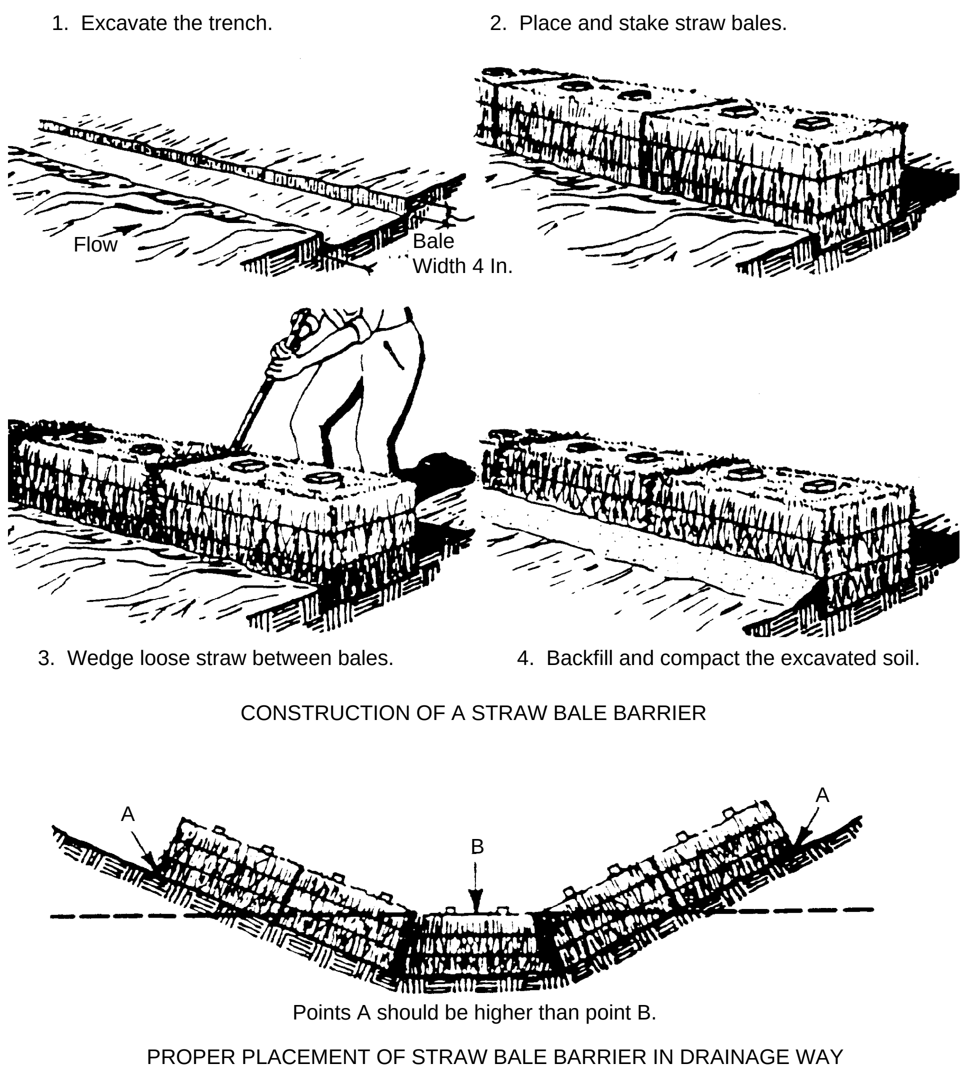


**Figure 7. Proper installation of straw bale fences (3).**

4. Are the bales installed in a 4-in. trench, as shown in Figure 7, and backfilled with 4 in. of soil on the upslope side?

5. Are the bales forced together as tightly as possible and anchored with at least two stakes or pieces of rebar per bale driven toward the previous bale and flush with the top of the bale?

6. Are gaps wedged with straw, and is straw spread on the upslope side?

7. Are straw bale fences used in channels with concentrated flow only when velocities are low and placed as shown in Figure 7 (perpendicular to flow and extending at least one bale length above the mid-channel bale)?

Maintenance checks:

1. Is it necessary to replace the fence to maintain all of the above conditions?

2. Is sediment removal needed (before it reaches 1/2 the height of the fence)?

2.2. Settling ponds

Settling ponds have several advantages. They can function through all construction phases and have relatively low maintenance requirements. They can also be located to intercept runoff both before and after the onsite drainage system is developed.

The three types of settling ponds in use differ only in their outlet structure. The term sediment basin is used to describe a settling pond with a pipe outlet that generally serves a drainage area of 3 to 10 acres. A sediment trap is a settling pond with a stable spillway outlet and a smaller service area. The third type is a permanent water quantity control pond put in temporary service during construction; such a pond is designed to drain completely between storms in permanent service. This operating mode is not appropriate for ESC application, however, because the residence time is too short for good particle trapping and settled material becomes resuspended during draining. Therefore, a temporary riser outlet needs to be installed for use during construction.

A key point in the design and construction of a settling pond is to avoid short-circuiting by the water. Short-circuiting can cut the actual residence time far below the theoretical value and harm performance. Ways of avoiding it are to divide the pond into two or more cells, locate the inlet and outlet far apart, and install baffling to increase the flow path.

2.2.1. Sediment basin (see Figure 8)

Installation checks:

1. Is the bottom graded to be as level as possible?

2. Is the pond no deeper than 7 ft with 1 ft of freeboard?

3. Are side slopes no steeper than 3 horizontal to 1 vertical?

4. Does the pond have an emergency spillway that is 1 ft deep, with a width two to three times the number of acres served by the pond, and lined with 2 to 4 in. of rocks?

5. Does the pond discharge through a riser pipe having at least two 1-in. diameter orifices at the top of the sediment storage zone?

6. Are inlet and outlet areas protected from erosion with riprap?

7. Is baffling installed if the length-to-width ratio is less than 6 or if the entrance velocity is high?

8. A good feature to prevent short-circuiting of flow is a two-celled pond, preferably with cells divided by sandbags or a rock berm and connected by a riser pipe similar to that used for the outlet. A less preferred arrangement is dividing the pond with a filter fabric fence. Is this feature installed if specified in the design?

9. Is the pond fenced if it presents any safety hazard to children?

Maintenance checks:

1. Is sediment removal needed (before 1.5 ft accumulates)?

2. Are any outlet orifices clogged and in need of cleaning?

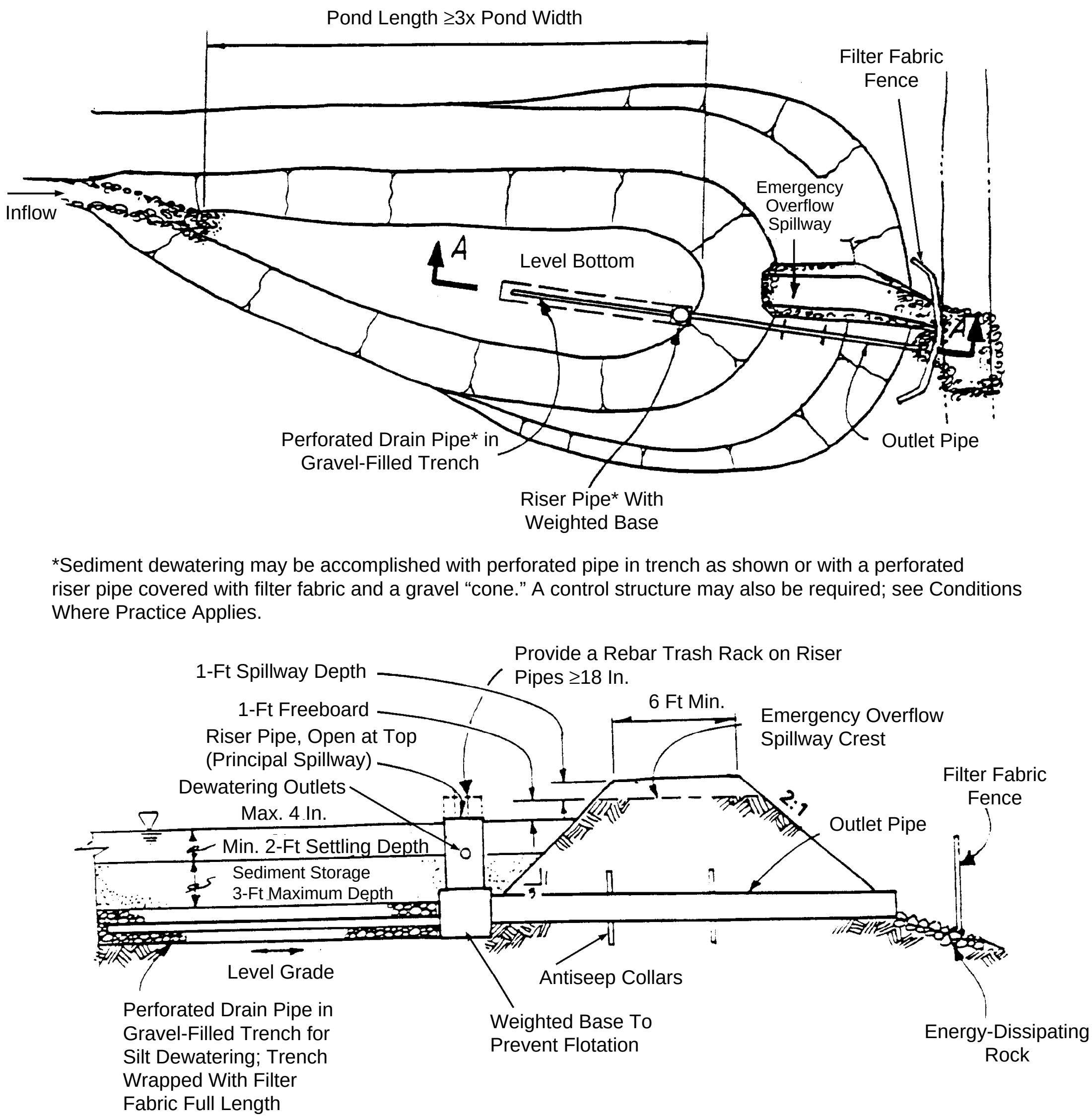


**Figure 8. Typical sediment basin (3).**

3. Are any embankments damaged and in need of compaction or rebuilding?
4. Has riprap or spillway lining material been lost and need to be replaced?
5. Are there signs of excessive drainage to the pond, requiring rerouting or pond enlargement?
6. Are there signs of excessive sediment loading to the pond, requiring stabilization of the drainage area?

3. Management of other construction site pollutants

Construction sites can create pollution problems over and above erosion and sediments through paving operations, handling and storage of various materials, spills, and waste handling. Inspectors should also be aware of the potential for runoff contamination from these sources and inspect the site according to the following guidelines.

3.1. Handling cement and concrete

Inspection checks:

1. Do concrete trucks have a designated washout area with a sediment trap?

2. Is exposed-aggregate driveway wash water drained toward a collection point at the side or into a sediment trap, where it cannot get into a street drainage system?

3.2. Material storage and handling

Inspection checks:

1. Are weather-resistant enclosures used for the storage and handling of materials, such as paints, coatings, wood preservatives, pesticides, fuels, lubricants, and solvents, and for potentially polluting wastes?
2. Are there designated and clearly communicated procedures for handling materials and wastes and washing containers?
3. Is a chemical inventory maintained, including Material Safety Data Sheets?
4. Are containers and enclosures inspected periodically for leakage, indicating the need for maintenance?

3.3. Spill containment

Inspection checks:

1. Has a spill control plan been developed, and have supplies been obtained to implement it? Does the plan include:

   Who to notify if a spill occurs?

   Specific instructions for different products?

   Who is in charge?

   Spill containment procedures?

   Easy to find and use spill cleanup kits?

   How a spill will be prevented from getting into a drainage system (e.g., valving, diversion, absorption)?

   A disposal plan?

   A worker education program?

3.4. Waste management

Inspection checks:

1. Have waste reduction practices been instituted (e.g., reusing solvents, substituting for toxic products, minimizing quantities of materials used)?
2. Have recycling practices been instituted (e.g., waste separation for recycling, purchasing recycled materials)?
3. Are hazardous and nonhazardous wastes separated and each disposed of properly and promptly?
4. Has an employee education program on waste management been established?

## Inspection Programs for Permanent Drainage Practices and Facilities

### *Program Development*

#### Program Elements

The following elements are recommended for a comprehensive inspection program for permanent drainage practices and facilities:

- Stormwater management planning
- Plan review process
- Construction inspection and enforcement process
- Followup inspection and long-term maintenance process

The stormwater management planning step ensures that each site considered for a permit receives comprehensive analysis. The extensive considerations in this portion of the recommended program are beyond the scope of this discussion. The third element refers to inspection of the stormwater management facilities themselves when they are built to determine whether installation has been consistent with the approved plans. The final element seeks to ensure that facilities continue to operate properly. The next subsection covers programmatic aspects of the followup inspection and long-term maintenance process. The discussion is then extended in the following section to examples of inspection guidelines for common practices and facilities.

#### Followup Inspection and Long-Term Maintenance Process

Recommended features for a followup inspection and maintenance program are:

- An ordinance designating public authority and public and private responsibilities.
- A tracking system.
- An inspection schedule.
- A maintenance schedule.
- A safety program.
- A citizen response program.
- A detailing of proper waste disposal practices.
- A maintenance contractor education program.

The discussion below elaborates on several of these features, drawing principally on experience in King County, Bellevue, Olympia, and elsewhere in the Puget Sound region of Washington. The examples in the section that follows this discussion present guidance on establishing schedules for common facilities and the specific checks to be made during inspection visits.

**Public Versus Private Responsibilities.** Whereas inspection is usually a public function, the question of responsibility often arises with respect to the upkeep of privately owned facilities. One model involves establishing a multiyear bonding period, during which the developer has all responsibility. Often after this period and a demonstration of effective operation, the government agency responsible for stormwater management then takes over operation and maintenance. A second model calls for leaving maintenance as a private function (performed by a commercial property owner or homeowners' association), with inspection by the public agency. In this approach, the government assumes the responsibility and assesses costs if the private party does not meet its responsibility. Effective application of this strategy requires that private maintenance contractors competently perform the needed work. The frequent lack of qualified contractors requires government agencies to consider training and certifying them.

**Tracking System.** King County, Washington, offers a useful model for a tracking system to organize long-term inspections and maintenance. The King County approach uses a computerized information system. Each inspector is assigned an inventory of facilities to inspect and specify maintenance and is given a laptop computer to use in the field. The information system contains an identification number for each facility, its type (e.g., wet pond, infiltration basin), location, any special needs, and data on previous experiences. At the conclusion of each visit, the inspector enters a maintenance needs assessment in the computer database. The computer then generates a maintenance work order.

**Safety.** Safety is a major consideration because of potentially harmful air quality in below-ground spaces, corroded supports, traffic, falling objects, sharp edges, poisonous plants and insects, and lifting. The safety portion of an inspection and maintenance program should include:

- Testing instruments for harmful atmospheres (explosive, containing hydrogen sulfide, lacking in oxygen); a tester should be capable of checking all potential conditions of concern, and all enclosed spaces should be tested before an inspector enters.
- Ventilating equipment.
- Checking for structural soundness before entering a manhole.
- Traffic warning devices.
- Ladders, safety harnesses, and hard hats.
- Removing poisonous plants and threatening insect nests.
- Adequate personnel.
- Safety training.

**Waste Handling.** Major maintenance on large facilities should be scheduled when the least runoff is expected. It is often a good idea to use ESC-type installations such as filter fabric fences, sandbags, grassed drainage areas, and revegetation to prevent escape of sediments during maintenance.

Although the vactor truck is the maintenance workhorse, a problem concerns mixing waste that may be relatively clean with very dirty waste. A solution, but an expensive one, is to have "clean" and "dirty" trucks. Another issue concerns disposal of both solids and separated "decant" water picked up by vactor trucks. The best solution for decant water is to discharge it to a special decant station that has sediment and oil separation equipment, before the water is discharged to a sanitary sewer. Few facilities currently operate this way, and most vactor waste is discharged directly to a sanitary sewer. This practice can result in pollutants entering surface waters because of inadequate treatment at the municipal wastewater plant. It can also deliver toxic materials that can upset biological processes at the treatment plant. Guidelines are needed but generally do not exist for disposing of solids. The best programs now send them to a lined municipal landfill, unless they fail a "looks bad and smells bad" test, in which case they are treated as hazardous waste.

## *Permanent Drainage Practices and Facilities and Their Inspection*

### Categories of Practices and Facilities

Following is the breakdown of practices used by Reinelt (2), with the number of individual practices in each category:

1. Stormwater devices—three practices
2. Detention facilities—eight practices
3. Infiltration facilities—five practices
4. Biofilters—three practices

The 19 practices represented include some variations on common devices, depending on their intended function, as specified by the Stormwater Management Manual for the Puget Sound Basin (3). For example, detention facilities include "wet ponds," which have a quantity control function, and "water quality wet ponds," which are treatment devices.

The following passages provide inspection checklists for example practices and facilities, generally the most common, in each category. The practices and facilities themselves are described only very briefly in this section. For detailed descriptions, consult a stormwater management manual or textbook. The checklists are divided into checks to make when the practice or facility is first installed and checks to be made on each followup visit to determine the need for maintenance. Many of the points are illustrated in diagrams that accompany the checklists. Also presented for a number of practices are tables of maintenance standards. These tables have been developed over time in the Puget Sound area, and several jurisdictions have contributed to them.

While much of an inspector's work is performed in the field, it is often advisable or even absolutely necessary to do some background work in the office before going out to inspect an installation. This work mainly consists of consulting the design plans to determine the specifications.

Too infrequent inspection and maintenance is one of the main reasons for poor performance by stormwater facilities. The frequency of followup inspections should be determined based on the type of device and the circumstances where it is installed. An inspection and maintenance plan should be developed before an installation goes into service. As a general rule, surface facilities should undergo a drive-by inspection at least monthly and after any rain totaling 0.5 in. or more in 24 hr.

1. Stormwater devices

   This group includes devices used for collection and conveyance of stormwater, as well as special-purpose facilities. Within the category are catch basins, pipes and culverts, and oil/water separators. Inspection guidelines are given for oil/water separators as a complete example. Tables of maintenance standards are included for the other types of facilities.

   1.1. Oil-Water separators

   Figure 9 illustrates the three basic types of oil-water separators. The spill control unit's purpose is to catch small spills; it is not capable of separating dispersed oil. The American Petroleum Institute (API) separator is a baffled tank that can separate "free" (unemulsified) oil but requires a relatively large volume for effectiveness. The coalescing plate (CP) separator can separate free oil in a much smaller volume because of the large surface area provided for oil collection by the corrugated plate pack. The following guidelines generally apply to all types, except as noted.

   Installation checks

   1. Is the type appropriate for the service?
   2. Is the unit sized and installed as specified in the plans?
   3. Are adequate removable covers provided for observation and maintenance?
   4. Is runoff excluded from roofs and other areas unlikely to contain oil?
   5. Is any pump in use placed downstream to prevent mechanical emulsification?
   6. Is detergent use avoided upstream to prevent chemical emulsification?
   7. For API and CP separators, is a forebay provided sized at 20 $ft^2$ of surface area per 10,000 $ft^2$ of drainage area?
   8. For API and CP separators, is an afterbay provided for placement of absorbents?
   9. For the CP separator, are the plates no more than 3/4 in. apart and at 45 to 60 degrees from horizontal?

   Maintenance checks:

   1. Is weekly inspection performed by the owner?
   2. Are oil and any solids removed frequently enough (at least just before the main runoff period and then after the first major runoff event)?
   3. Are absorbents replaced as needed, but at least at the beginning and end of the main runoff season?
   4. Is the effluent shutoff valve operational for closure during cleaning?
   5. Are waste oil and solids disposed of as specified by regulations?
   6. Is any standing water that is removed discharged to the sanitary sewer and then replaced with clean water?

   1.2. Pipes and culverts

   Refer to Table 2 for a summary of maintenance standards for conveyance facilities.

   1.3. Catch basins

   Catch basins are routinely placed between the drain inlets in streets and parking lots and the conveyances that transport water away to settle large solids. Refer to Table 3 for a summary of maintenance standards.

2. Detention facilities

   Detention facilities include ponds that are designed and operated either to drain within hours after a

**Table 2. Maintenance Standards for Pipes and Culverts**

| Defect | Conditions When Maintenance Needed | Maintenance Results |
|---|---|---|
| Sediment and debris | Accumulated sediment that exceeds 20% of the diameter of the pipe. | Pipe cleaned of all sediment and debris. |
| Vegetation | Vegetation that reduces free movement of water through pipes. | All vegetation removed so water flows freely through pipes. |
| Damage | Protective coating is damaged; rust is causing more than 50% of deterioration to any part of pipe. | Pipe repaired or replaced. |
| | Any dent that decreases the end area of pipe by more than 20%. | Pipe repaired or replaced. |
| Debris barriers | Trash or debris that is plugging more than 20% of the openings in the barrier. | Barrier clear to receive capacity flow. |
| Damaged/ Missing bars | Bars are bent out of shape more than 3 in. | Bars in place with no bend >3/4 in. |
| | Bars are missing or entire barrier is missing. | Bars in place according to design. |
| | Bars are loose and rust is causing 50% deterioration to any part of barrier. | Repair or replace barrier to design standards. |

storm (dry ponds), to drain within a day or two (extended-detention dry ponds), or to retain a permanent or semipermanent pool (wet ponds). These ponds can have water quantity control objectives, or water quality control objectives, or both, although dry ponds offer few water quality benefits. Detention facilities also include below-ground concrete vaults and storage pipes, the latter sometimes referred to as tanks. These devices serve primarily quantity control purposes, although if they have relatively long water residence times they can collect some solids. Other facilities sometimes included in this category are parking lot and rooftop storage. Constructed wetlands can be placed in either this group or with biofilters. Inspection guidelines are given for wet ponds as a complete example. A table of maintenance standards is included for vaults and tanks as well.

### 2.1. Wet ponds

Figure 10 illustrates a typical wet pond. A wet pond has a “dead storage” permanent or semipermanent pool and a “live storage” zone that fills during runoff events and then drains fairly quickly. Its design basis differs depending on its purpose (quantity control or quality control, or both), but the checks made when it is installed and later while it is operating are

**Table 3. Maintenance Standards for Catch Basins**

| Defect | Conditions When Maintenance Needed | Maintenance Results |
|---|---|---|
| Trash and debris (including sediment) | Trash or debris of more than 1/2 $ft^3$ located in front of the catch basin opening or is blocking capacity of basin by >10%. | No trash or debris located immediately in front of catch basin opening. |
| | Trash or debris in the basin that exceeds 1/3 to 1/2 the depth from the bottom of the basin to the invert of the lowest pipe into or out of the basin. | No trash or debris in catch basin. |
| | Trash or debris in any inlet or outlet pipe blocking more than 1/3 of the height. | Inlet and outlet pipes free of trash or debris. |
| | Dead animals or debris that could generate odors that would cause complaints or dangerous gases. | No dead animals or vegetation present. |
| | Deposits of garbage exceeding 1 $ft^3$ in volume. | No garbage in catch basin. |
| Structural damage to frame or top slab | Corner of frame extends more than 3/4 in. past curb face into the street (if applicable). | Frame is even with curb. |
| | Top slab has holes larger than 2 $in.^2$ or cracks wider than 1/4 in. (intent is to make sure all material runs in to basin). | Top slab is free of holes and cracks. |
| | Frame not sitting flush on top slab (i.e., separation of >3/4 in. of the frame from top of slab). | Frame is sitting flush on top of slab. |
| Cracks in basin walls or bottom | Cracks wider than 1/2 in. and longer than 3 ft, any evidence of soil particles entering catch basin through cracks, or structure is unsound. | Basin replaced or repaired to design standards. |
| | Cracks wider than 1/2 in. and longer than 1 ft at the joint of any inlet/outlet pipe or any evidence of soil particles entering catch basin through crack. | No cracks more than 1/4 in. wide at joint of inlet/outlet pipe. |
| Settlement/ Misalignment | Basin has settled more than 1 in. or has rotated more than 2 in. out of alignment. | Basin replaced or repaired to design standard. |
| Fire hazard | Presence of chemicals such as natural gas, oil, and gasoline. | No flammable chemicals present. |
| Vegetation | Vegetation growing across and blocking >10% of basin. | No vegetation blocking opening to basin. |
| | Vegetation (or roots) growing in inlet/outlet pipe joints that is >6 in. tall and <6 in. apart. | No vegetation or root growth present. |
| Pollution | Nonflammable chemicals of >1/2 $ft^3$ per 3 ft of basin length. | No pollution present other than surface film. |

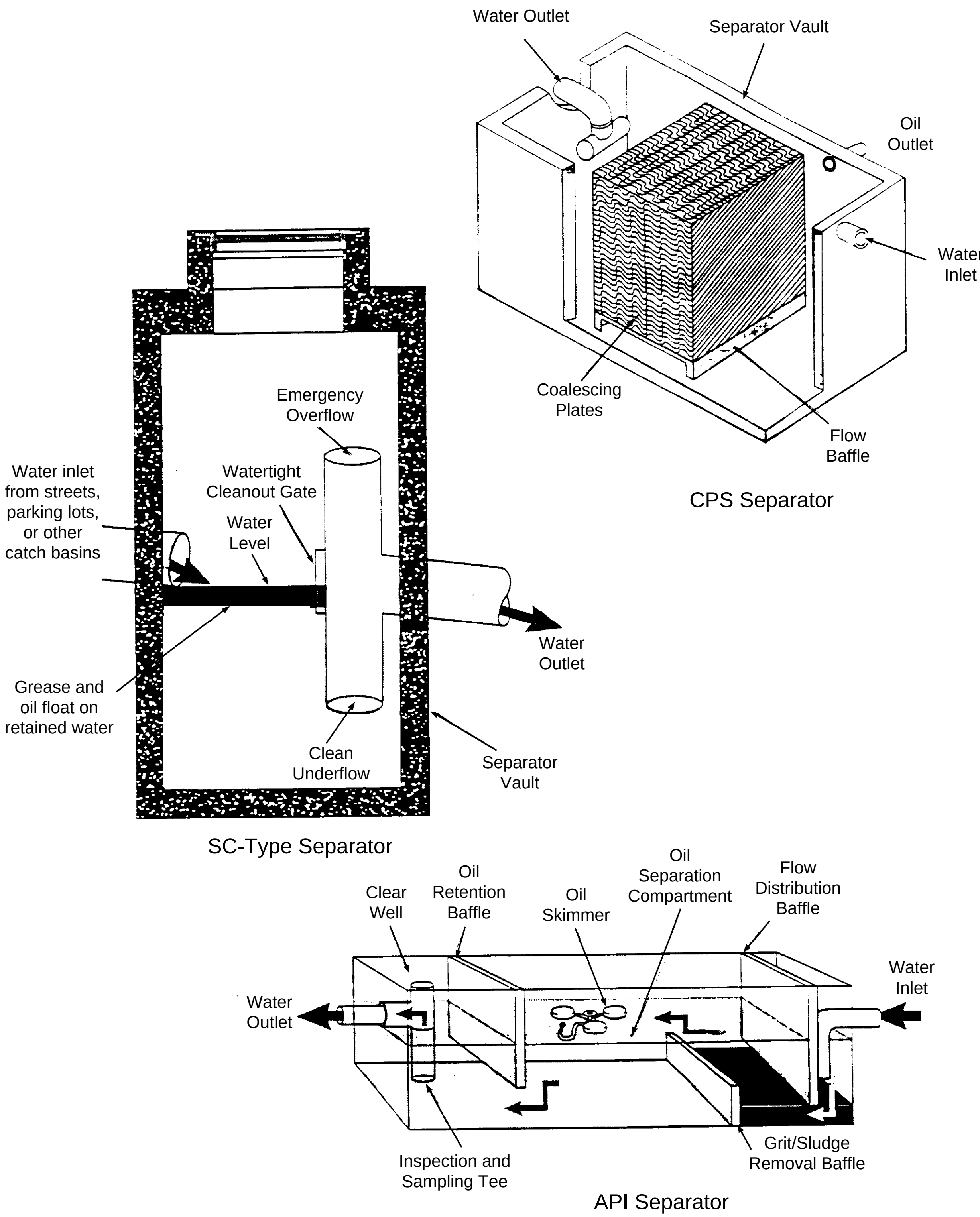


**Figure 9. Types of oil/water separators (3).**

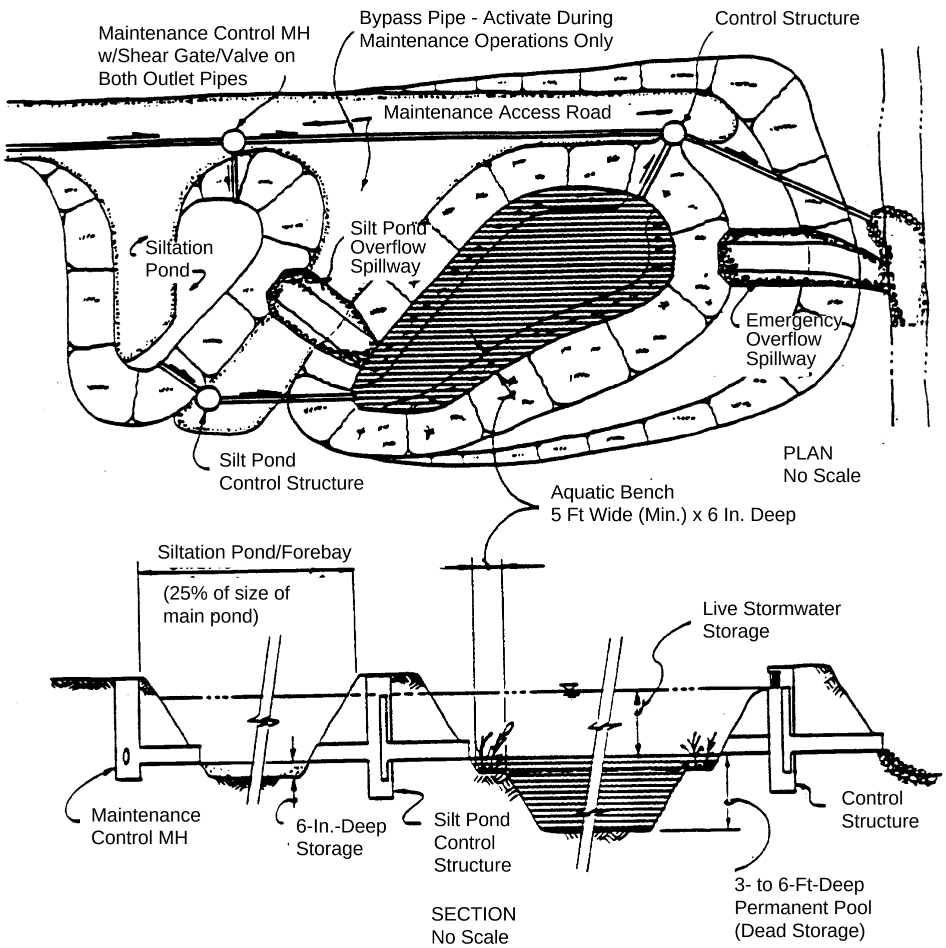


**Figure 10. Typical wet pond (3).**

generally the same, with the few exceptions noted.

Installation checks:

1. Does construction comply with local requirements for earthwork, concrete, other masonry, reinforcing steel, pipe, water gates, metalwork, and woodwork?
2. Are all dimensions as specified in the approved plan?
3. Are interior side slopes no steeper than 3 horizontal to 1 vertical and exterior side slopes no steeper than 2:1?
4. Is the bottom level?
5. Are the spillways (between cells, if any, and the emergency outlet spillway) sized and reinforced as specified in the approved plan?
6. Is a drain provided that can drain the dead storage zone within 4 hr if necessary?
7. Are inlet and outlet areas stabilized as necessary to avoid erosion?
8. Are safety concerns addressed, for example, with such features as a shallow bench completely around the edge of the pond, barrier plantings to discourage approach by children, and/or fencing (should not be necessary if sloped as recommended and other safety features are provided)?
9. For a water quality pond, is the effective length-to-width ratio at least 3:1 minimum, 5:1 preferably; are the inlet and outlet separated to the greatest width possible?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?
2. Refer to Table 4 for specific checks and maintenance standards (these standards apply to other types of ponds as well).

**Table 4. Maintenance Standards for Detention Facilities**

| Defect | Conditions When Maintenance Needed | Maintenance Results |
|---|---|---|
| Trash and debris | Any trash or debris that exceeds 1 $ft^3$/ 1,000 $ft^2$. There should be no evidence of dumping. | Trash and debris cleared from site. |
| Poisonous vegetation | Presence of any poisonous vegetation that constitutes a hazard to maintenance personnel or to the public (e.g., poison oak, stinging nettles, devil's club). | No evidence of poisonous vegetation. Coordinate with health department. |
| Pollution | One gallon or more of oil, gas, or contaminants, or any amount that could 1) cause damage to plant, animal, or aquatic life, 2) constitute a fire hazard, 3) be flushed downstream during storms, or 4) contaminate ground water. | No contaminents present other than surface film. Coordinate with local health department. |
| Unmowed grass/ ground cover | In residential areas, mowing is needed when the cover exceeds 18 in. in height. Otherwise match facility cover with adjacent ground cover and terrain as long as there is no decrease in facility function. | Grass/ground cover should be mowed to 2 in. Maintain dense cover on slopes and in bottom of dry ponds. |
| Rodent holes | Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes. | Rodents destroyed and dam or berm repaired. Coordinate with local health department. |
| Insects | When insects such as wasps or hornets interfere with maintenance activities. | Insects destroyed or removed from site. Coordinate with people who remove wasps for antivenom protection. |
| Tree growth | Tree growth does not allow maintenance access or interfere with maintenance activity. If trees are not interfering with access, leave trees alone. | Trees do not hinder maintenance activities. |
| Erosion of pond side slopes | Eroded damage >2 in. deep where cause of damage is still present or where there is potential for continued erosion. | Slopes stabilized with appropriate erosion control BMPs (e.g., seeding, mats, riprap). |
| Sediment accumulation in forebay/pond | Accumulated sediment 10% of the design forebay/pond depth, or every 3 yr. | Sediment cleaned out to design depth. Reseed if necessary for erosion control. |
| Dike settling | Any part of dike that has settled >4 in. | Dike is rebuilt to design elevation. |
| Rocks missing from overflow spillway | Only one layer of rock above native soil in an area of 5 $ft^2$ or greater, or any exposed soil. | Rock replaced to design standard. |
| Inadequate spillway size | Emergency overflow or spillway not large enough to handle flows from large storm events. | Increase capacity of spillway to current design standards. |
| Missing, broken, or damaged fencing | Any defect in fencing that permits easy entrance to the pond. | Fencing repaired to prevent entrance. |
| | Damaged fencing including posts out of plumb by >6 in., top rails bent >6 in., missing or loose tension wire, missing or sagging barbed wire, missing or bent extension arms. | Repair fencing and barbed wire to design standards |
| | Fencing parts that have a rusting or scaling condition that is affecting structural adequacy. | Structurally adequate posts or parts with protective coating. |
| | Opening in fencing that allows passage of an 8-in. diameter ball. | No opening in fence. |
| Erosion under fencing | Erosion >4 in. deep and 12 to 18 in. wide, permitting an opening under fence. | No opening under fence >4 in. |
| Missing or damaged gates | Missing or damaged gate, locking device, or hinges. | Gates, locking devices, and hinges repaired. |
| | Gate is out of plumb >6 in. and out of design alignment >1 ft. | Gate is aligned and vertical. |
| | Missing stretcher bar, bands, or ties. | Stretcher bar, bands, and ties in place. |
| Blocked or damaged access roads | Debris that could damage vehicle tires. | Roadway free of debris. |
| | Obstructions that reduce clearance above road surface to <14 ft (e.g., tree branches, wires). | Roadway clear overhead to 14 ft. |
| | Any obstructions restricting access to a 10- to 12-ft width for a distance of >12 ft, or any point restricting access to a width of <10 ft. | Obstructions moved to allow at least a 12-ft access route. |
| | Any road settlement, potholes, mushy spots, or ruts that prevent or hinder maintenance access. | Road surface repaired and smooth. |
| | Weeds or brush on or near road surface that hinder access, or are >6 in. tall and <6 in. apart within a 400 $ft^2$ area. | Weeds and brush on or near road surface cut to 2 in. |
| | Erosion within 1 ft of the roadway >8 in. wide and 6 in. deep. | Shoulder and road free of erosion. |

2.2. Vaults and tanks

Refer to Table 5 for a summary of maintenance standards for closed detention systems.

3. Infiltration facilities

Infiltration facilities discharge most of the entering water to the ground. They include surface basins and trenches, below-ground perforated pipes, roof drain systems, and porous pavements. Inspection guidelines are given for infiltration basins as a complete example. A table of maintenance standards is included for infiltration trenches as well.

3.1. Infiltration basins (see Figure 11 for a typical basin)

Installation checks:

1. Does construction comply with local requirements for earthwork, concrete, other masonry, reinforcing steel, pipe, water gates, metalwork, and woodwork?

2. Are all dimensions as specified in the approved plan?

3. Does the timing of basin construction avoid the entrance of any runoff containing sediment from elsewhere on the site?

4. Is the basin preceded by a pretreatment device (e.g., presettling basin or biofilter) to prevent failure caused by siltation?

5. Is the basin at least 50 ft from any slope greater than 15 percent and at least 100 ft upslope and 20 ft downslope of any building?

6. Is the outlet orifice design consistent with the infiltration capacity on which the facility is based (e.g., to avoid the collection of more water than can infiltrate in 48 hr)?

7. Are the spillways (between cells, if any, and the emergency outlet spillway) sized and reinforced as specified in the approved plan?

8. Are all disturbed areas stabilized to prevent erosion?

9. After final grading, has the bed been deeply tilled to provide a well-aerated, highly porous surface texture?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?

2. Refer to Table 6 for specific checks and maintenance standards.

**Table 5. Maintenance Standards for Closed Detention Systems**

| Defect | Conditions When Maintenance Needed | Maintenance Results |
|---|---|---|
| Plugged air vents | Half of the end area of a vent is blocked at any point with debris and sediment. | Vents free of debris and sediment. |
| Debris and sediment in storage area. | Accumulated sediment depth is >10% of the diameter of the storage area for 1/2 the length of storage vault or any point exceeds 15% of the diameter. Example: 72-in. storage tank would require cleaning when sediment reaches a depth of 7 in. for more than 1/2 the tank length. | All sediment and debris removed from storage area. |
| Cracks in joints between tank/pipe sections | Any crack allowing material to be transported into the facility. | All joints between tanks or pipe sections are sealed. |
| Problems with manhole cover | Cover is missing or only partially in place. Any open manhole requires maintenance. | Manhole is closed and secured. |
| | Locking mechanism cannot be opened by one maintenance person with proper tools. Bolts into frame have <1/2 in. of thread (may not apply to self-locking lids). | Mechanism is repaired or replaced so it functions properly. |
| | Cover difficult to remove by one maintenance person applying 80 lb of lift. | Cover can be removed and reinstalled by one maintenance person. |
| Ladder rungs of manhole unsafe | Local government safety officer or maintenance person judges that ladder is unsafe due to missing rungs, misalignment, rust, or cracks. | Ladder meets design standards and allows for maintenance access. |
| Catch basins | See Table 3. | See Table 3. |

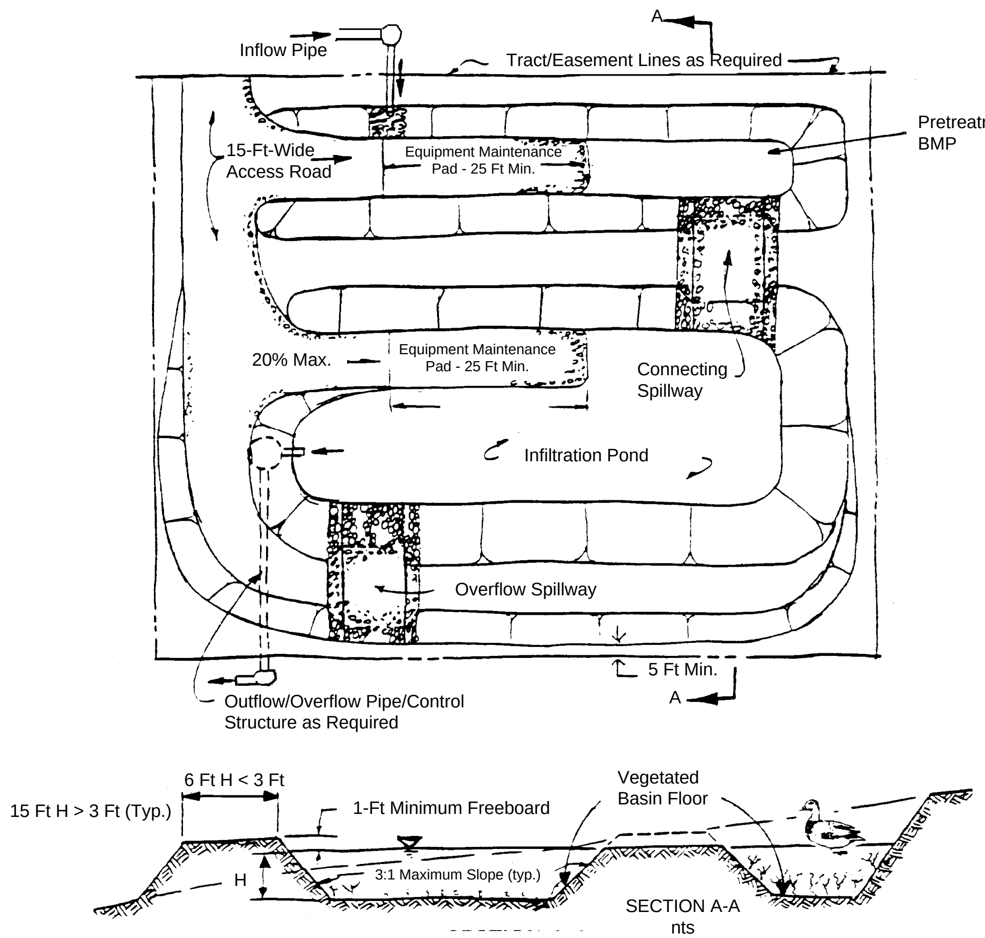


**Figure 11. Typical infiltration basin (3).**

3. In addition, is tilling necessary to restore infiltration capacity (regular annual tilling is recommended)?

3.2. Infiltration trenches

Refer to Table 7 for a summary of maintenance standards for infiltration trenches.

4. Biofilters

The term “biofilter” applies to vegetated land treatment systems. Biofilters can be in the form of vegetated swales, in which water flows at some measurable depth or in a thin sheet across broad surface areas, sometimes called “filter strips.” Constructed wetlands are also sometimes put in this category. The guidelines given below generally pertain to swales and filter strips, although some exceptions are noted. Inspection of constructed wetlands should be conducted with reference to both these guidelines and those given above for wet ponds.

4.1. Biofiltration swales and filter strips

Installation checks:

1. Are the dimensions and plantings as specified in the approved plan?
2. Is the vegetation cover dense and uniform?
3. If the biofilter is a swale, is it parabolic or trapezoidal in shape, with side slopes no steeper than 3 horizontal to 1 vertical?
4. Is the biofilter placed relative to buildings and trees in such a way that no portion will

**Table 6. Maintenance Standards for Infiltration Basins**

| Defect | Condition When Maintenance Needed | Maintenance Results |
|---|---|---|
| Sediment buildup in system | Soil texture test indicates facility is not functioning as designed. | Sediment is removed and/or facility is cleaned so that system works according to design. A forebay or presettling basin is installed to reduce sediment transport to facility. |
| Poor facility drainage (more than 48 hr) | Soil texture test indicates facility is not functioning as designed. | Additional volume added through excavation to provide needed storage. Soil aerated and rototilled to improve drainage. |
| Sediment trapping area | Sediment and debris fill >10% of sediment mapping facility or sump. | Sediment trapping facility or sump cleaned of accumulated sediment. |
| No sediment trapping facility | Stormwater enters infiltration area without pretreatment. | Trapping facility (presettling basin, detention pond, biofilter) is added before infiltration facility. |

**Table 7. Maintenance Standards for Infiltration Trenches**

| Defect | Condition When Maintenance Needed | Maintenance Results |
|---|---|---|
| Sediment and debris buildup in trench | By visual inspection, little or no water flows through the trench during large storms. | Debris blocking infiltration trench is removed. Gravel in infiltration trench is replaced or cleaned. |
| Observation well | Observation well buried, covered, or inaccessible. | The observation well/cap is accessible to the inspector for opening and inspection. |
| Water percolates up from trench | Trench water or water with dye percolating to surface. | Gravel and filter fabric in infiltration trench is replaced or cleaned. Trench functions according to design standards. |
| Filter fabric exposed | Filter fabric is exposed or damaged. | Filter fabric is replaced or repaired and covered with proper backfill material. |

be shaded throughout the day and possibly experience poor plant growth?

5. If the longitudinal slope is less than 2 percent or if the water table can reach the root zone of vegetation, is water-resistant vegetation planted to survive a standing water condition or is an underdrain system installed to assist drainage (note: underdrains may not be practical with a large filter strip)?

6. If the longitudinal slope is in the range of 4 to 6 percent, are check dams provided approximately every 50 to 100 ft to reduce velocity (note: check dams may not be practical on a larger filter strip)?

7. If the slope on which a swale is installed exceeds 6 percent, does it traverse the slope in such a way that no reach slopes more than 4 percent, or 6 percent with check dams?

8. Is the lateral slope entirely uniform to avoid any tendency for the flow to channelize?

9. Is flow introduced in such a way that entrance velocity is dissipated quickly, flow is distributed uniformly, and erosion is avoided (e.g., by using a riprap pad or some means of level spreading)?

10. Was construction-phase runoff excluded or was the biofilter reestablished after construction, and are upslope areas stabilized to avoid erosion into the biofilter?

11. Is a bypass in place for flows larger than the flow rate for which the biofilter is designed to provide runoff treatment, or is the facility sufficiently large to pass at least the 100-yr, 24-hr storm without eroding (a bypass is preferred to maintain the treatment function and prevent resuspension of settled material)?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?

2. Refer to Table 8 for specific checks and maintenance standards.

**Table 8. Maintenance Standards for Biofilters**

| Defect | Conditions When Maintenance Needed | Maintenance Results |
|---|---|---|
| Trash and debris | Dumping of yard wastes. Accumulation of nondegradable materials. | Remove degradable wastes and compost. Recycle other waste when possible. |
| Sediment buildup | Accumulation >20% of design depth. | Cleaned or flushed to match design. Vegetation restored as necessary. |
| Poor vegetation cover | Vegetation sparse and/or weedy. Overgrown with woody vegetation. | Aerate soil and plant. Remove woody growth and replace. |
| Erosion damage to slopes | Erosion >2 in. deep where cause still present or potential exists for continued erosion. | Find cause and eliminate. Stabilize with appropriate erosion controls (e.g., seeding, mat, mulch). |
| Conversion to use incompatible with water quality control | Filled, planted appropriately, or blocked. | Discuss with nearby property owners and specify corrections to be made. |
| Poor drainage | Water stands in swale. | Determine cause. If water table is high, consider rebuilding with liner or underdrain. If slope <1%, use underdrain. |

## References


1. Reinelt, L.E. 1991. Construction site erosion and sediment control inspector training manual. Seattle, WA: Engineering Continuing Education, University of Washington.
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