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Protecting Natural Wetlands

A Guide to Stormwater Best Management Practices

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A Guide to Stormwater Best Management Practices

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Contents

Acknowledgements

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Section 1
Introduction

Overview

Although wetlands have long been recognized for their flood control and water quality improvement functions, there is an increasing concern that unrestricted use of natural wetlands as receptacles for point and nonpoint sources of pollution, such as urban stormwater and other diffuse sources of runoff, will have an adverse effect on wetlands and wetland biota. As a result of this concern, the U.S. Environmental Protection Agency (EPA), in cooperation with the State of Florida, the Association of State Floodplain Managers, Inc., and the Association of State Wetland Managers, sponsored a workshop in January 1992 on wetlands and stormwater. The purpose of the workshop was to investigate various issues related to the management of stormwater and wetlands, explore potential options, and learn from the experiences of the participants (wetland scientists, engineers, and environmental managers) about protection of natural wetlands that receive stormwater runoff.

One of the major findings of the workshop was that wetlands in urban areas can be dramatically altered by uncontrolled runoff resulting from natural drainage or direct discharge to wetland systems. Consequently, workshop participants included in their final recommendations a need for guidelines to provide a framework for baseline protection of wetlands that receive stormwater runoff. This document is a first step toward providing such guidelines. The purpose of this document is to describe the potential benefits, limitations, and appropriate application of best management practices (BMPs)[1] that can be implemented to protect the functions of natural wetlands from the impacts of urban stormwater discharges and other diffuse sources of runoff. This document is not designed to recommend specific management practices that would be applicable under all circumstances. Instead, it presents information to assist managers in making informed decisions concerning the appropriate use of BMPs to protect existing wetland resources.

. . . wetlands in urban areas can be dramatically altered by uncontrolled

Land use changes within a watershed that accompany urbanization can result in a variety of impacts to wetlands and other receiving waters. As the percentage of impervious surface increases with the building of roads, parking lots, and buildings, resulting runoff volume, velocity, and pollutant loads can increase dramatically. Increases in impervious surfaces also reduce the opportunity for the rainfall or snowmelt

[1]BMPs can include planning, schedules of activities, prohibitions of practices, maintenance procedures, and other management approaches necessary to prevent or reduce the pollution of waters of the United States.

to infiltrate, thereby lowering groundwater levels. The impacts of these changes on wetlands can be severe, but they will vary depending on a number of factors including the natural hydrology of the system, the degree of change in the landscape, and the size and type of wetland being affected.

Where natural wetlands are the ultimate receivers of stormwater, either inadvertently or by design, the potential for impacts to the wetlands (through changes in hydrology or water quality) exists, and BMPs may be necessary to minimize these impacts. Existing wetland characteristics need to be matched with site characteristics as well as stormwater characteristics when selecting BMPs. Management practices can be designed to preserve existing wetlands in a watershed in their current state so they can continue to provide water quality improvement and other functions and/or to restore degraded wetlands. BMPs designed to control stormwater can result in potential impacts on downstream wetlands as well as the wetlands directly receiving stormwater discharge. Therefore, the impacts to both onsite and offsite wetlands should be considered when determining the suitability of wetlands for receiving stormwater and when selecting and designing stormwater BMPs to protect the functions of natural wetlands.

The ecological attributes of natural wetlands can be adversely affected as watersheds develop and stormwater flows increase. Wetlands tend to exist in dynamic equilibrium with surrounding conditions when activities in a watershed remain constant. Changes in the volume or quality of stormwater runoff resulting from changing activities in a watershed can affect the functions and values of a natural wetland by altering the hydrologic, water quality, and sediment or soil characteristics of a wetland. Alteration of the physical and chemical characteristics of a wetland can adversely affect the biological community and result in negative impacts to the ecological functions of a wetland.

As discussed in Section 2 of this document, the hydrologic conditions in a wetland affect abiotic factors such as salinity, soil oxygen availability, and nutrient availability These factors in turn greatly influence the flora and fauna present in a wetland. Water depth and the natural hydroperiod in a wetland also directly influence vegetative composition and density, primary productivity, organic accumulation, nutrient cycling and availability, and the types and density of aquatic and terrestrial fauna in a wetland. Stormwater inflows to wetlands can directly affect the natural hydrology of wetlands by changing water depths and altering the hydroperiod of the systems.

The impacts of stormwater runoff on the water quality in a wetland are dependent on the volume and composition of the stormwater. Pollutants found in runoff from urban areas tend to include sediments, oxygen-demanding substances, nutrients, heavy metals, pesticides, hydrocarbons, increased temperature, and trash and debris (see Section 2). Changes in turbidity, oxygen levels, and water temperature in a wetland can have direct impacts on the flora and fauna in the wetland. In addition, the assimilation of heavy metals, pesticides, and hydrocarbons associated with stormwater runoff by the flora and fauna in a wetland can result in negative impacts to the ecological characteristics of the wetland.

The morphological characteristics of the soils in a wetland can also be changed as a result of introducing stormwater runoff into a wetland system. Changes in the texture of a wetland soil can result from changes in the amount or particle size of sediments that enter the wetland system. Changes in the texture of a wetland soil can affect the hydrology of the system by changing wetland drainage characteristics. Adsorption of pollutants in stormwater runoff by suspended sediments can result in the incorporation of heavy metals, hydrocarbons, nutrients, and bacteria into the soil when the sediments settle out of suspension. The pollutants can later reappear throughout the wetland ecosystem via chemical transformations, vegetative uptake, or resuspension.

The Code of Federal Regulations (CFR) provides definitions of “waters of the United States” and “wetlands” at 40 CFR 122.2 (a) through (g). Because wetlands are included under this definition of waters of the United States, their water quality must be protected to meet the mandate of the CWA articulated in sectionl0l(a) "to restore and maintain the chemical, physical, and biological integrity of the nation’s waters.” The protection of water quality must address not only the water chemistry, but also the multiple elements, including aquatic life, wildlife, habitat, vegetation, and hydrology, that together make up aquatic systems. Therefore, relevant issues to address with respect to wetlands protection include the toxicity and bioaccumulation of pollutants, diversity and composition of aquatic species, entrapment of pollutants in sediment, habitat loss, and hydrologic changes.

Controlling stormwater runoff into natural wetlands can benefit the ecosystem by helping to maintain natural conditions in the system. As mentioned, changes in the hydrology, water quality, and/or soil characteristics of a wetland resulting from stormwater inflows can result in shifts in the character of the wetland habitat, which in turn changes the overall ecological characteristics of the system. Maintaining natural conditions in a wetland by controlling upstream stormwater runoff can mitigate the impacts of a developing watershed on the ecological attributes of a wetland by helping to maintain predevelopment hydrologic, water quality, and soil conditions.

Implementation of BMPs to protect wetlands from runoff can include watershed planning techniques and also site-specific structural approaches. The planning approaches are generally preferable to the structural practices. However, where planning has failed or is no longer an option, implementation of structural controls, including retrofitting stormwater management facilities into BMPs, may be appropriate.

Some general guiding principles to use in protecting wetlands from stormwater and nonpoint source runoff include the following:

- Wetlands serve valuable water quality functions; however, wetlands have a limited capacity for handling increased flows or additional pollutants.
- The use of BMPs specifically designed to mitigate impacts to wetlands might offset some of the impacts of stormwater runoff by controlling increased volumes and velocities of runoff. However, BMP discharges to wetland can adversely affect wetland functions and values.
- BMPs have the potential to reduce impacts to downstream wetlands or wetlands directly receiving stormwater discharges. To reduce the impacts to a receiving wetland, BMPs should be selected based on site-specific conditions, as well as regional variability in stormwater characteristics, climate conditions, urban development patterns, soil types, and wetland types.
- There might be opportunities to use degraded urban wetlands or wetlands in arid areas to provide final polishing treatment or to restore some wetland functions (e.g., hydrology), provided there is adequate treatment of the stormwater before it is discharged to a wetland.
- Stormwater management should be integrated within other programs at the federal, state, and local levels. Basinwide planning is needed to address stormwater manage-

ment objectives and wetland protection goals (i.e., advance planning, watershed management plans, state wetlands conservation plans, or other planning tools).

- Because wetlands have a limited capacity to mitigate increased flows of stormwater and increased pollutants, any proposal to use natural wetlands for final polishing of treated stormwater discharges should include monitoring and maintenance as components of the plan.
- In urbanizing areas, former wetlands whose vegetation has been removed and hydrology altered to the extent that they no longer function as wetlands (e.g., prior converted croplands), can offer valuable opportunities to restore wetland functions.
- While additional research is needed, existing studies suggest that constructed wetlands can provide better pollutant removal and more consistent, predictable filtering of stormwater than natural wetlands. Constructed wetlands should therefore be located upstream of natural wetland locations, so their treated discharges can be directed to natural wetlands or other waters.
- Multiple BMPs in series, or the 'treatment train" approach, whereby a series of BMPs provide alternative nonstructural approaches (e.g., watershed planning) or various structural control techniques (i.e., grassed swales or longer flow paths to settle solids, regulate flow, and reduce pollutants), may provide greater protection for natural wetlands than individual BMPs.

Using This Manual

Although a number of manuals describe best management practices to be used to address stormwater runoff, this manual is a first attempt at addressing the specific water quality concerns related to wetlands. It is intended for use by anyone addressing potential impacts to wetlands from stormwater runoff, and it presents a wide range of planning approaches as well as specific BMPs that can be employed in a variety of situations. Regardless of what type of approach is taken, and at what level, this manual should be used as a starting point in a process to identify and evaluate appropriate BMPs to protect wetland resources (see Figure l-l).

The information in this document is presented in four sections. Section 2 describes the factors (wetland and stormwater characteristics) that should be considered when developing BMPs to protect wetlands and their natural functions from the potential impacts of stormwater discharges and other diffuse sources of runoff. Wetland factors to consider include wetland type, hydrology, climate, and site-specific conditions. Stormwater factors to consider include the quantity and quality of runoff and the frequency of runoff events.

...this manual is a starting point to identify appropriate BMPs to protect wetland resources.

Although they are described separately, the wetland factors and stormwater factors are closely related. For example, climate influences the frequency and intensity of storm events; the wetland type affects the capacity of the wetland to handle a given quantity or quality of stormwater runoff; and the functional attributes of a particular wetland can be severely affected by the introduction of even small amounts of certain contaminants. When deciding what BMPs may be appropriate for a particular situation, both sets of variables-wetland factors and stormwater factors-should be considered individually and in combination. Helpful tables that detail these factors (for example, wetland types or typical

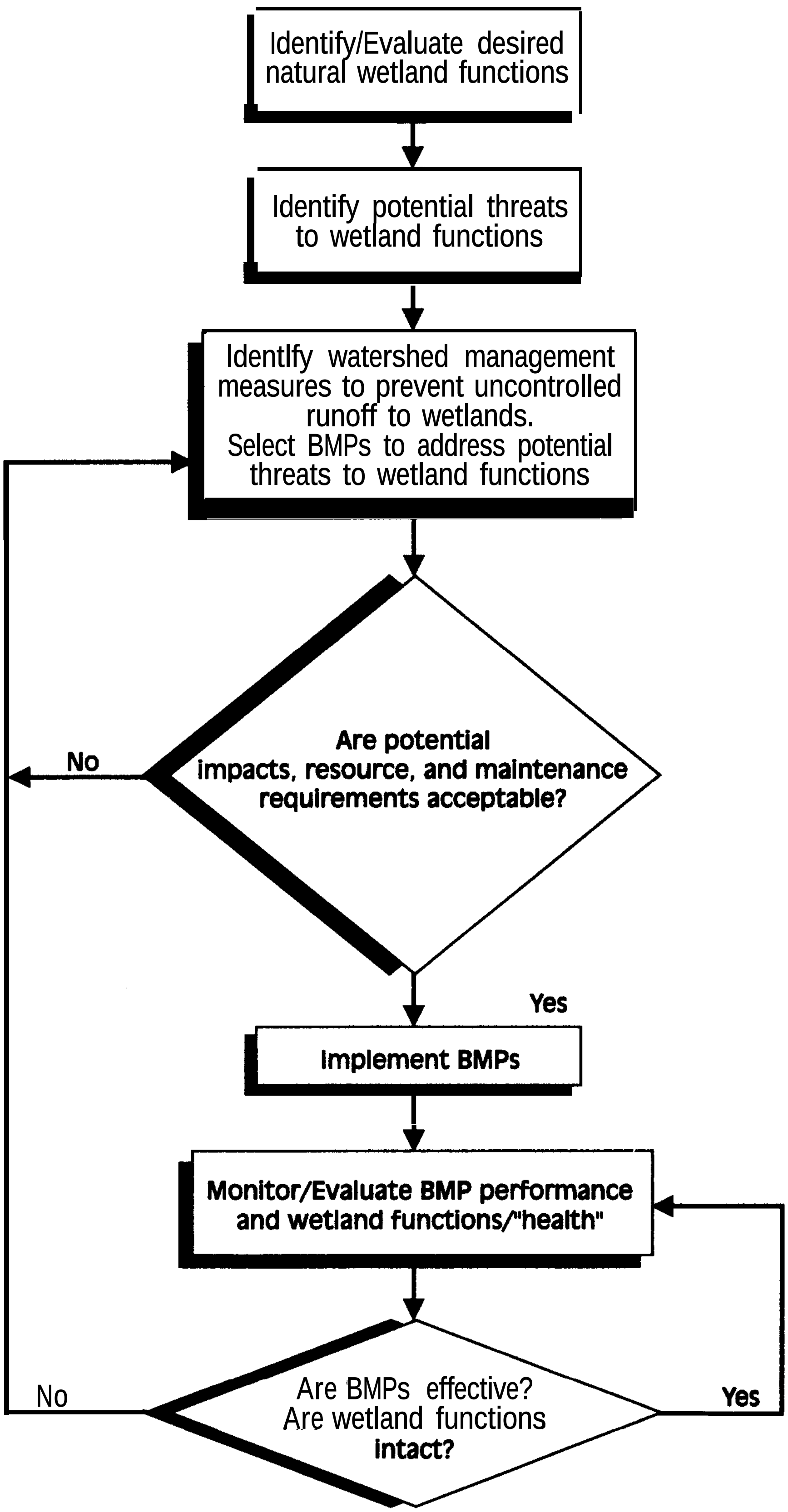

Figure l-l. How to use this manual.

See discussion of wetland factors and types (consider wetland functions, soils, climate, hydrology, etc.), pp. 2-2 to 2-17.

See discussion of stormwater factors (land use, climate, etc.) pp. 2-17 to 2-26.

See benefits to wetland functions (Table 2-7) p. 2-42.

See description of BMPs and BMPs in series in Section 4. Consider potential impacts to wetland functions, and capital and maintenance costs.

See Case Studies (Section 3) and BMP Fact Sheets (Section 4) for information on implementation of BMPs.

See page 244 for overview of monitoring.

pollutants found in stormwater runoff) are provided in Section 2 to assist managers in considering the factors in depth. A third set of factors-the characteristics of potential BMPs-should also be considered in combination with the wetland and stormwater factors. An overview of BMPs for controlling the effects of stormwater on the functions of natural wetlands is provided in Section 2; details are provided in the BMP fact sheets in Section 4.

Section 3 of this document presents several case studies that describe examples of situations where BMPs were used to protect natural wetland functions from the impacts of runoff and to restore the functional quality of degraded wetlands. Case studies were selected from both arid and nonarid climates, as well as from temperate and colder climates. Some of the case studies include an in-depth overview of a particular experience using BMPs to protect wetlands, whereas others present only anecdotal information. Since states have only recently had stormwater management programs in place, or will begin implementation of such programs within the next decade, only a limited number of well-documented case studies show the effectiveness of stormwater management BMPs and natural wetlands.

Section 4 presents fact sheets describing specific BMPs and their potential relationship to natural wetlands. For each BMP, a fact sheet is provided with the following information: definition and purpose of the BMP, its scope and applicability, design criteria considerations, potential effects on wetlands (i.e., benefits and limitation for use), cost-effectiveness (where applicable), maintenance, and sources of additional information. BMPs included in this document represent examples of some of the more commonly used practices. Numerous BMP manuals from state and local governments throughout the country were used to gather the information presented in the fact sheets.

Section 2
Factors to Consider When Selecting BMPs

Introduction

Best management practices (BMPs)-both structural and nonstructural[1]- are used to protect natural wetlands from the impacts of stormwater and other diffuse or nonpoint sources of runoff,[2] including changes in wetland hydrology or water quality When natural wetlands are the final discharge point, BMPs may be used to provide preliminary treatment of runoff that might impact the receiving natural wetland. Natural wetlands, usually by virtue of their position in the landscape, directly receive stormwater runoff. In this case, BMPs should be used to control the runoff-outside the wetland-to maintain the wetland's existing hydrology and functions. BMPs should be selected after carefully considering the combination of variables that influence a potentially impacted wetland and the characteristics of the runoff entering that particular wetland, as well as the capabilities and applicability of the potential BMPs.

Wetland factors to consider include wetland type, hydrology, biological functions, and site-specific conditions. A consideration of stormwater factors should consist of an evaluation of the geographical area producing runoff, including existing and future impervious surfaces and stormwater infrastructure, quantity and quality of runoff, and the frequency of runoff events. Factors like zoning and changes in planned land use should also be considered to evaluate the potential impacts from future development on the quantity and quality of stormwater and the ability of existing treatment systems to control the runoff adequately. BMP capabilities include factors such as flood storage; infiltration; and sediment, nutrient, and pollutant removal.

By evaluating the wetland characteristics in concert with the stormwater characteristics, and applying the appropriate BMPs described in Section 4, the effects on the wetland system can be minimized. For example, if it is anticipated that a certain type of development will cause higher sediment loading to receiving waters and the wetland on the site is sensitive to increased sedimentation, BMPs that control sedimentation should be employed to minimize the effects on the wetland.

Wetland factors, stormwater factors, and BMP capabilities are described in this section. This information can be used when evaluating the BMPs presented in Section 4.

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[1]Structural best management practices are those practices which entail construction of human-made structures (USEPA, 1992b). Examples of structural BMPs include infiltration basins, sand filters, vegetated filter strips, and constructed wetlands. Nonstructural best management practices are regularly scheduled activities or programmatic actions (USEPA, 1992b). Examples of nonstructural BMPs include pollution prevention, watershed planning, vegetated buffer areas, street sweeping, inspections, and improved materials-handling practices.

[2]For the purpose of this document, the term *runoff* should be interpreted to include stormwater discharges and nonpoint sources of pollution, including urban sources. These other sources of nonpoint pollution can include agriculture, forestry, marinas, and hydromodification activities. The reader should refer to Guidance *Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, 1993) for additional information on all sources of nonpoint pollution.

Wetland Factors

Wetlands are integral parts of a watershed; their position in the landscape is influenced by and influences the characteristics of a watershed. Wetlands can function as nutrient sinks, temporary water storage areas, groundwater recharge areas, and critical wildlife habitat. Natural and anthropogenic (human-induced) activities within a watershed influence the functions of natural wetlands. When these activities remain relatively constant, the functions of natural wetlands tend to exist in dynamic equilibrium with the surrounding conditions. However, changes in the established combination of natural and anthropogenic activities within a watershed can result in dramatic changes in the functions of natural wetlands.

The physical, chemical, and biological characteristics of natural wetlands combine to determine unique wetland types. Differences in these characteristics range from subtle to obvious among different wetland types depending on many factors associated with wetlands that include, but are not limited to, hydrology, biological functions, site-specific factors, the climate and geology of the region, landscape position, and soils. These factors are not independent, but form a complex interrelationship to make each wetland type unique.

An assessment of the current status of these factors for a particular wetland is important to understand the effects of certain factors, such as increased or decreased quantities of stormwater runoff, on an individual wetland. Understanding the interactions of a particular wetland with the other watershed features provides a broader and more comprehensive perspective of impacts of various activities within the wetland and the watershed as a whole. For example, by changing the hydrology of a wetland, the water retention and sediment attenuation functions can be lost, resulting in downstream hydrological and water quality impacts; or vegetative species and composition within and surrounding a wetland might change, resulting in habitat quality changes.

Some of the factors affecting wetland type are influenced more by stormwater runoff than others. For the purpose of this document, hydrology, biological functions, soils, and site-specific conditions are considered to be factors that can be significantly affected by stormwater runoff. Other factors, such as climate and landscape position (which might be linked to hydrology), are a function of the location of a particular wetland. They are not affected by stormwater runoff, but they contribute significantly to the determination of wetland type.

Selection and design of stormwater BMPs should consider the wetland type, hydrology, biological functions, site-specific features, and other wetland factors, as well as the relationship of the wetland to other watershed features, including climate. Additionally, the impacts of a particular BMP need to be considered in the context of both the individual wetland and the entire watershed to determine potential impacts on other resources.

Wetland Type

The effects of stormwater on a particular wetland depend, in part, on the type of wetland in question. Wetland type can be defined as the combination of attributes (e.g., physical, chemical, and biological) that make a particular wetland different from other wetlands. A wide range of wetland types, which are the result of the cumulative effect of many environmental variables, exist in the United States. In an effort to bring precision and standardization to the classification of wetland types, Cowardin and others (1979) developed *Classification of Wetlands and Deepwater Habitats of the United* States for use in the National Wetlands Inventory Their classification system breaks wetlands into systems, subsystems, and classes analogous to plant or animal taxonomic classifications.

The classification system developed by Cowardin and others (1979) is very comprehensive. However, because it contains too much detail for this document, a simpler classification system, proposed by Mitsch and Gosselink (1993), is used here. [3] In their classification system, Mitsch and Gosselink (1993) divided wetlands into two major groups--coastal and inland-as shown in Table 2-1. Some wetlands in the United States are not adequately described by the Mitsch and Gosselink (1993) classification system, but the system is intended as only a preliminary guide to evaluate wetlands.

Table 2-1. Types of Wetlands

Wetland Type	*Cowardin et al., 1979 Equivalent*
Coastal Wetlands	
Tidal salt marshes	Estuarine intertidal emergent, haline
Tidal freshwater marshes	Estuarine intertidal emergent, fresh
Mangrove wetlands	Estuarine intertidal forested and shrub, haline
Inland Wetlands	
Inland freshwater marshes	Palustrine emergent
Northern peatlands	Palustrine moss-lichen
Southern deepwater swamps	Palustrine forested and scrub-shrub
Riparian wetlands	Palustrine forested and scrub-shrub

Source: Adapted from Mitsch and Gosselink, 1993.

Hydrology

Hydrology is described by Mitsch and Gosselink (1986) as probably the *most important factor in the establishment and maintenance of specific types of wetlands and wetland processes.* Precipitation, surface water inflow and outflow, groundwater exchange, and evapotranspiration are the major factors influencing the hydrology of most wetlands. Figure 2-l shows a simplified diagram of a wetland hydrologic cycle.

Mitsch and Gosselink (1986) concluded that *hydrologic conditions are extremely important for the maintenance of a wetland's structure and function, although simple cause-and-effect relationships are difficult to establish.* Hydrologic conditions affect many abiotic factors, including salinity, soil oxygen levels (which can cause anoxia), and nutrient availability. These abiotic factors, in turn, determine the flora and fauna that develop in a wetland. Finally, biotic components are active in altering the wetland hydrology completing the cycle.

[3] The reader should refer to Cowardin and others (1979) if a more detailed classification system is needed

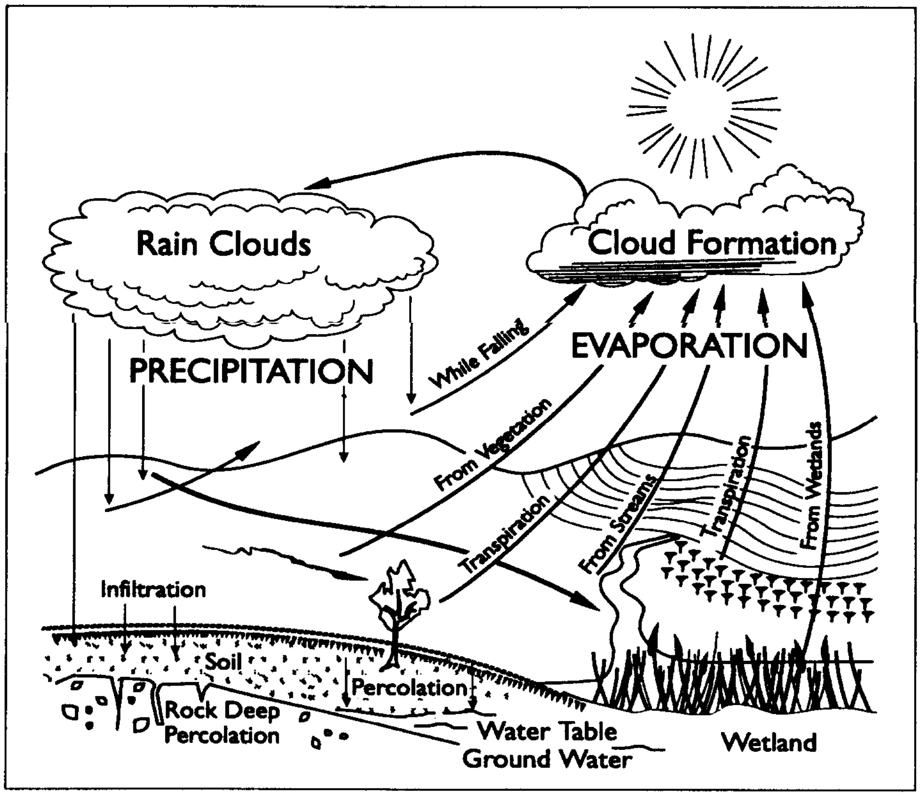

Figure 2-1. Wetland Hydrological Cycle.

Some wetlands remain permanently inundated or saturated, some are wet for only a short period during the year; and others may remain dry over periods of several years. The periods of saturation or dryout in wetlands have strong implications for the characteristic structures that develop in wetlands (Kadlec and Knight, 1996). Each wetland type exhibits a unique hydroperiod that is fundamental in the stability of a wetland system. *Hydroperiod* is defined as the periodic or regular occurrence of flooding and/or saturated soil conditions (Marble, 1992). Mitsch and Gosselink (1986) suggested characterizing hydroperiod as the ratio of flood duration divided by flood frequency over a given period of time. Cowardin and others (1979) provided general descriptions of hydroperiod for both tidal and nontidal wetland systems (listed in Table 2-2). The hydroperiod for a particular wetland is a function of the water budget (i.e., inflow and outflow water balance) and storage capacity, which is affected by the surface contours of the landscape and subsurface soil, geology, and groundwater conditions (Mitsch and Gosselink, 1986).

Since wetlands typically represent a transition between terrestrial and open-water ecosystems, the effects of changed hydrology are extremely variable. Several principles outlining the importance of hydrology to wetlands have been described by Mitsch and Gosselink (1986) and include the following:

1. Hydrology leads to a unique vegetation composition, but can limit or enhance species richness. For example, different species of vegetation respond differently to flooding and large trees tolerate flooding better than seedlings.
2. Primary productivity in wetlands is enhanced by flowing conditions and a pulsing hydroperiod. Primary productivity is often depressed by stagnant conditions.

Table 2-2. Definitions of Wetland Hydroperiods

Hydroperiod	*Definition*
Tidal wetlands	
Subtidal	The substrate is permanently flooded with tidal water.
Irregularly Exposed	The land surface is exposed by tides less often than dally.
Regularly Flooded	Tidal water alternately floods and exposes the land surface at least once dally.
Irregularly Flooded	Tidal water floods the land surface less often than dally.
Nontidal Wetlands	
Permanently Flooded	Water covers the land surface throughout the year in all years. Vegetation is composed of obligate hydrophytes.
Intermittently Exposed	Surface water is present throughout the year except in years of extreme drought.
Semipermanently Flooded	Surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land surface.
Seasonally Flooded	Surface water is present for extended periods, especially early in the growing season, but is absent by the end of the season in most years. When surface water is absent, the water table is often near the land surface.
Saturated	The substrate is saturated to the surface for extended periods during the growing season, but surface water is seldom present.
Temporarily Flooded	Surface water Is present for brief periods during the growing season, but the water table usually lies well below the soil surface for most of the season. Plants that grow both in uplands and wetlands are characteristic of the temporarlly flooded regime.
Intermittently Flooded	The substrate is usually exposed, but surface water is present for variable periods without detectable seasonal periodicity. Weeks, months, or even years may intervene between periods of inundation. The dominant plant communities under this regime may change as soil moisture conditions change.
Artificially Flooded	The amount and duration of flooding are controlled by means of pumps or siphons in combination with dikes or dams. Vegetation present cannot be considered a reliable indicator of water regime.

Source: Adapted from Mitsch and Gosselink, 4993; Cowardin et al., 1979.

3. Organic accumulation in wetlands is controlled by hydrology through its influence on primary productivity, decomposition, and export of particulate organic matter.
4. Nutrient cycling and nutrient availability are both significantly influenced by hydrologic conditions.

Changes in the natural hydrology of a wetland can therefore affect many of the functions of a wetland. When volumes of stormwater runoff to a wetland increase, or when a wetland is impounded to treat stormwater runoff, changes to the biotic and abiotic characteristics can occur. For example, hydrologic disturbance of a wetland can cause a shift from a function as a sink for nutrients and metals toward a function as a source of these materials, thereby affecting other functions within the wetland and in downstream communities (Brinson, 1988).

Biological Functions

Because wetlands are transition zones between uplands and aquatic systems, they can serve as exporters of organic materials and sinks for inorganic matter (Mitsch and Gosselink, 1993). Because of this transitional position in the landscape, some wetlands have high biodiversity, whereas others are very productive in terms of biomass. Wetlands typically provide habitat to a variety of microbial and plant species due to presence of ample water. The diversity of physical and chemical interactions that occur in wetlands results in a continuum of flora and fauna from the smallest of microbes to large trees. Interactions resulting from the biological diversity in wetlands results in greater diversity, more complete utilization of energy inflows, and ultimately the emergent properties of the wetland ecosystem (Kadlec and Knight, 1996). The biological communities that become established in wetlands are typically made up of a rich mixture of microbes, plants, and animals.

The established biological community in a particular wetland exists in a state of dynamic equilibrium with the physical and chemical properties associated with that wetland. Actions that upset the established balance found in the biological community, such as changes in the hydroperiod, volume of runoff, or water quality, lead to significant changes in the functions of a wetland. For example, increasing the volume of stormwater runoff that enters a wetland can stress indigenous vegetation and allow more flood-tolerant species of vegetation (e.g., *Typha)* to take over a wetland.

Microbes

In wetlands, microbes are major transformers of organic and inorganic materials. The population of microbes in a wetland varies according to many factors, but usually it is composed of aerobic species at the surface of the substrate and shifts to anaerobic species as the depth increases. As facilitators for the many biochemical reactions that occur in wetlands, wetland microbes have adapted to a wide range of substrate conditions. Aerobic bacteria colonize areas around plant roots to take advantage of the oxygen-rich rhizosphere surrounding the roots of wetlands vegetation. Other anaerobic microbes play important roles in the chemical reactions that produce methane, nitrogen gas, and hydrogen sulfide. Mychorrhizial fungi facilitate nutrient uptake, reduce stress, enhance salt tolerance, and increase the initial growth and survival of wetland plants (USDA-SCS, 1992).

Vegetation

Wetland vegetation comes in many forms, including floating, rooted, emergent, submergent, herbaceous, and woody. Wetland plants transport oxygen from their leaves to the rhizosphere surrounding their roots. This soil oxygenation process is important for many of the microbial reactions that take place in wetlands. Other functions of wetland vegetation include trapping sediment and removing nutrients or other pollutants from the water column and substrate (USDA-SCS, 1992). Wetland plants provide habitat for a variety of fish and wildlife. All species of fish and wildlife need habitat-food, water, and cover-for survival. The habitat value of a particular wetland site depends on the quantity, quality, diversity, and seasonality of the food, water, and cover that it offers (PSWOA, 1990).

Animals

Wetlands support many different types of animals, including invertebrates, fish, amphibians, reptiles, birds, and mammals. Because of the transitional nature of wetlands, both aquatic and terrestrial animals live in wetlands. Wetlands provide food sources, protection from weather and predators, resting sites, reproductive sites, and molting grounds for wildlife (Cooper, 1989). Wetlands provide this habitat function for many species of fish and wildlife, including some that are threatened or endangered. Many species of animals that are not typically considered to be wetland species spend a part of their life-cycle or fulfill daily requirements in wetlands. Other species like the beaver and muskrat can alter wetlands as a result of their activities (USDA-SCS, 1992).

Site-Specific Conditions

Although wetlands in rural or undeveloped areas might be relatively pristine, they can be affected by agricultural activities, particularly sedimentation and drainage. Wetlands in previously developed urban areas can be affected by changes in surface water and groundwater hydrology or water quality. In drier areas, some existing urban wetlands are hydrologically dependent on treated wastewater inputs, which are subject to variable water use practices. Wetland plant communities can be altered as a result of hydrologic or physical disturbances. Exotic or invasive plant species, which become established more easily in disturbed ecosystems, might be present, affecting the existing plant species and habitat functions of the wetland. Also, natural buffer areas surrounding urban wetlands might have been eliminated, lowering the diversity of the wetland system and reducing areas for wildlife refuge.

Wetlands in temperate climates undergo seasonal variation in biological activity, which is a major factor in many wetland processes involving the retention or transformation of pollutants. Some wetland types can serve as a sink for nutrients during the growing season and as a source at other times of the year (Mitsch and Gosselink, 1986), making consideration of the seasonal distribution of runoff important.

Soils

Soils and their characteristic properties develop as the result of interactions between parent material, climate, plant and animal life, relief, and time. The degree of influence of each of the five factors generally varies from place to place. In a given location one factor can dominate in the formation of a soil and determine most of its properties (Smith and Matthews, 1975).

Soils that form in a wetland environment are classified as hydric and have morphological characteristics that result under wet conditions. Hydric soils are defined by the Natural Resources

Conservation Service (NRCS) as soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in their upper part. Hydric soils are classified as either organic or mineral soils based on the percentage of organic material in their upper part (see Table 2-3). General differences in physicochemical characteristics between organic and mineral soils include percentage of organic content, pH, bulk density, porosity, hydraulic conductivity, water holding capacity nutrient availability, and cation exchange capacity (see Table 2-3).

Changes in the characteristics of a soil during its formation result from processes that include additions, removals, transfers, and transformations (Hall and Matthews, 1974). Modifying existing processes by placing BMPs adjacent to or upstream of a wetland can result in changes in wetland soil characteristics. For example, changes in the textural characteristics of a wetland soil can result from changes in the amount, type, and/or particle size of sediments that enter a wetland. The modification of soil textural characteristics can result in changes in the drainage characteristics of the wetland. For example, the percentage of coarse-grained sediments deposited in a wetland could be reduced by a stormwater BMP, resulting in a reduction of the soil's permeability over time. The reduced permeability could result in a reduction in the soil's ability to infiltrate water, thereby changing the character of the wetland.

The placement of BMPs adjacent to wetlands can result in changes to the chemical characteristics of the wetland soil if stormwater is not adequately treated prior to its discharge to the wetland. Suspended organic and inorganic particles tend to adsorb pollutants, such as heavy metals, nutrients, hydrocarbons, and bacteria (Stockdale, 1991). If the suspended particles are deposited in the wetland, the pollutants can become incorporated into the soils. Over a period of time pollutants that have accumulated in the soil can appear throughout the wetland environment via chemical transformations, vegetative uptake, or resuspension.

Additional changes to the chemical and morphological characteristics of a wetland soil can occur as the result of alterations to the natural factors affecting the soil's development. Changes to the natural characteristics (e.g., hydrology or vegetation) of a wetland can result in changes to

Table 2-3. Comparison of Mineral and Organic foils in Wetlands

Parameter	*Mineral Soil*	*organic soil*
Organic content	Less than 20%-35%	Greater than 20%-35%
pH	Usually circumneutral	Acid
Bulk Density	High	LOW
Porosity	LOW (45%-55%)	High (80%)
Hydraulic Conductivity	High (except for clays)	Low to high
Water Holding Capacity	LOW	High
Nutrient Availability	Generally high	Generally low
Cation Exchange Capacity	low, dominated by major cations	High, dominated by hydrogenion
Typical Wetland Type	Riparian forest, some marshes	Northern peatland

Source: Adapted from Mitsch and Gosselink, 1993.

the chemical transformations and nutrient cycling in a wetland soil. Redox potential, cation exchange capacity, pH, porosity, hydraulic conductivity, and the organic content of a soil can change as a result of altering the natural conditions within, or affecting, a wetland. Conversely, changes in the chemical and morphological characteristics of the soil in a wetland affect the overall characteristics of the existing wetland habitat.

Climate

Climate is defined as the average state of the atmosphere during a period of time-days, weeks, years, etc. (Rasmusson et al., 1993). Solar radiation is the primary external source of energy However, other external natural events (e.g., volcanic eruptions) and human-induced changes (e.g., land surface changes) also can affect climate (Rasmusson et al., 1993). Naturally occurring quantities and variations in rainfall and runoff are essential to the maintenance of many wetland types. Both the amount and seasonal distribution of rainfall and resulting runoff can play a role in determining the species composition, soil characteristics, and ecological functioning of inland wetlands. Factors such as precipitation patterns, including the frequency, intensity, and duration of storm events, determine the quantity and timing of runoff (Hammer, 1992). Other climatic factors, such as temperature, winds, relative humidity, and incident solar radiation, also affect wetlands.

Because hydrology is a particularly important factor, wetlands in arid and semiarid climates require water source investigations before a stormwater pretreatment strategy can be chosen. Whether wetlands in arid or semiarid climatic regions receive water from groundwater sources or from surface flows, maintaining adequate and natural inundation periods is crucial to their survival. Despite the significant reduction of hydrologic flows to wetlands by agricultural diversions, climate determines the fate of most aquatic habitats in arid and semiarid regions (Hutchinson et al., 1992). In arid and semiarid regions, precipitation should be considered a variable rather than a constant when planning surface water controls. Arid and semi-arid climates are largely responsible for the three distinct types of wetlands found in the American Southwest: ciengas, playas, and riverine wetlands.

Landscape Position

The location of a wetland in the landscape plays a role in the natural hydroperiod of the wetland, its retention of pollutants, and the effects of increased stormwater inputs. Brinson (1988) defined three major geomorphic wetland types based on location in the watershed:

- *Basin* -Wetlands typically in headwater regions that capture drainage from small areas and may receive precipitation as the primary source of water. Basins are characterized by fluctuations of the water table, a long hydroperiod, low hydrologic energy, and low nutrient levels. Plant communities usually consist of concentric zones of similar vegetation.
- *Riverine* -Wetlands that occur throughout the landscape and are primarily influenced by water flowing downstream. Riverine wetlands typically have short hydroperiods, high hydrologic energy, and high nutrient levels. Plant communities *are* usually arranged parallel to the direction of flow.
- *Fringe* -Wetlands that are usually located at the base of a drainage basin and adjacent to a large body of water, including estuarine areas. They generally have a long hydroperiod,

high hydrologic energy, and variable nutrient loads. Fringe wetlands are often influenced by frequent flushing by bidirectional flow. Zonation of vegetation is usually perpendicular to the direction of water flow.

Descriptions Of Specific Watland Types

Pocosin Wetlands

Pocosin wetlands occur along the Atlantic seaboard's lower coastal plain, from southern Virginia to northern Florida. Approximately 70 percent of pocosins are located in North Carolina. *Pocosin,* an Algonquin Indian word, literally means "swamp on a hill," which is an accurate description because pocosin wetlands are found in ridge and swale topography, as well as in flat areas of the lower coastal plain, in depressions of the Carolina Bays, in areas of springs and seeps in the upper coastal plain, and in the floodplains of streams. Pocosins contain dense evergreen plant communities, consisting of small broad-leaved evergreen trees (pondpine) and scrub shrubs (fetterbush and inkberry), which can occur either on highly organic soils, such as mucks or peats, or on very poorly drained mineral soils. Locally, there is wide species diversity. The soils of pocosins are acidic and low in nutrients and minerals. (Phosphorus is the limiting agent due to phosphorus-reducing microbes.) Pocosins occur in many different shapes and can vary tremendously in size from less than an acre to several thousand acres. These wetlands are important to birds and animals such as migratory waterfowl, herons, egrets, and muskrats.

Pocosin wetlands provide very favorable groundwater storage due to the differing permeability properties of their organic layers. Macropores in the upper layers make the soil very permeable, allowing for high retention of rainfall. Conversely, the reduced permeability of the lower layers, due to smaller pore spaces, prohibits the stored rainwater from draining very quickly. Because the base of a pocosin is not very permeable, the groundwater beneath the pocosin, which has a high mineral content, does not come into contact with the low-mineral-content water and soil of the pocosin. Water movement occurs as seepage at the pocosin's margins that flows to streams, or as direct flow to salt marshes in estuarine areas. These two principal properties of pocosins - attenuation of flow and continuous release of fresh groundwater- are essential to the estuarine ecology of the southeast Atlantic coast. These two properties also make pocosins particularly vulnerable to the adverse effects of stormwater discharges in the many areas of the lower coastal plain that are experiencing development.

Cienegas

Cienega is a term that usually applies to mid-elevation (1,008 to 2,000 m), or (3,281 to 6,562 ft) wetlands characterized by permanently saturated, highly organic, reducing soils (Hendrickson and Minckley, 1984). These warm, temperate habitats were most often termed cienegas by Hispanic and later explorers and settlers, and appear to be distinctive habitats (Hendrickson and Minckley 1984). The word cienega comes from the Spanish *cien aqua,* meaning "hundred waters." Cienegas are perpetuated by permanent, scarcely fluctuating sources of water, and are rarely subject to harsh winter conditions.

At mid-elevations of in semidesert grassland, cienegas are usually associated with perennial springs and headwater streams. They are near enough to headwaters that the probability of scouring from flood is minimal. Often, many meters of organic sediments have been deposited.

These wetlands are dominated by semiaquatic sedges, rushes, and grasses. Trees are scarce and immediate surroundings are saline as a result of capillarity and evapotranspiration (Hendrickson and Minckley, 1984). Historically grazed, more than 95 percent of the original cienegas have been lost (Hendrickson and Minckley, 1934). Many have been drained for development or destroyed by upstream pumping of the groundwater sources.

Playa Lakes

The term *playas* generally refers to areas occupied by temporary shallow lakes that have internal drainage, usually in arid to semi-arid regions. They are not part of an integrated surface drainage system, but are related to geologic fracture areas. Playas are shallow (typically less than 1 lm (3.28 ft) deep), circular basins averaging 15.5 acres (6.3 hectares) in surface area (Haukos and Smith, 1992). Playa floors are plate-like with relatively constant water depth throughout much of the basin. Because very few playas are directly associated with groundwater, playas can usually fill only from precipitation and irrigation runoff. Most playas are dry during one or more periods of each year, usually late winter, early spring, and late summer. Several wet-dry cycles during one year are not uncommon for a playa and depend on precipitation and irrigation patterns (Haukos and Smith, 1992). Soils of the playa are predominantly clays, differing from the loams and sandy loams of the surrounding uplands (Haukos and Smith, 1992). The climate of the region containing most of the playa lakes in the United States (southern Great Plains) is semi-arid in the west to warm temperate in the east. Vegetation in dry playas resembles upland vegetation and includes species such as summer cypress, ragweed, and various prairie grasses. Moist and flooded conditions in playas favor vegetation representative of other North American wetlands: barnyard grass, smartweed, bulrush, cattail, spikerush, arrowhead, toothcup, and dock (Haukos and Smith, 1992).

Although playas occur throughout the West, the following discussion focuses on a group of playas occurring in the High Plains of eastern New Mexico and northern Texas, and in an area south of the Arkansas River and north of the Canadian River. The playas in Texas are small marsh-like basins, 5 to 15 acres (2 to 6 hectares) in size, and are typically underlain by clay or fine sandy loam soils that are hydric. These shallow, circular lakes have individual watersheds of about 80 to 120 acres; the size of the watershed determines the size of the playa. The topography is flat to gently rolling, containing approximately 20,000 to 30,000 separate playa watersheds. The “wet” period of playas is seasonal, and their size and wet period depend on the intensity, duration, and frequency of precipitation and infiltration. Vegetation is diverse because it is influenced by varying salinity and depth and duration of saturated conditions. Tpically, playas demonstrate a pattern of concentric plant zonation of submerged and emergent aquatic species, such as pondweeds, arrowheads, and cattails, and lowland plants in wet meadows that surround the lakes. Many of these lakes are important migratory bird and songbird habitat.

Precipitation, ranging from 22 to 12 inches from east to west, is the major input since there are no permanent rivers and streams in the area. Excessive rainfall produces surface runoff in late spring and early fall. Other inputs, such as groundwater from deep aquifers and irrigation water, contribute to the permanence of standing water. Such groundwater input is uncommon because most playas are situated above the regional groundwater table. Because there is no surface water outflow, playas lose their water by evaporation, seepage, and irrigation use. However, an abundance of inflow of surface runoff in large enough quantities can result in some recharge to the High Plains aquifer. This occurs at the margins of the impermeable playas where more permeable sediments are found.

Since many of the playa watersheds function as cropland and rangeland, their vegetation serves an important purpose, helping to reduce excess nutrients from runoff and thereby improving the quality of surface water. In an area where water is not abundant, any addition to the groundwater will have economic significance, whether it be from irrigation water or recharge. Where playa watersheds receive stormwater discharges, the potential exists for adverse impacts to the playa itself or for degradation of the quality of the local and/or regional groundwater resources.

Riverina or Riparian Wetland Areas of the Southwest

Riverine or riparian wetlands exist along the margins of rivers, behind natural levees, in oxbows and floodplains. Riverine wetlands in arid climates are limited shoreward by desert and riverward by water depth and scouring. These wetlands are transitory They develop rapidly only to be removed by channel-straightening floods, or proceed toward an upland community after drying. In the American Southwest, riverine marshes are located in broad alluvial valleys distantly bounded by mountains. Like cienegas, riparian lands have been impacted by depletion of baseflow sources or by direct diversions upstream (Hawkins, 1993). A number of riparian wetlands exist, but some rely on other water sources such as treated upstream wastewater. The quality of the wastewater discharging to these wetlands plays a more important role in maintaining wetland functions than do the effects of stormwater runoff.

Prairie Potholes

The prairie pothole region of the northern United States consists of North Dakota, western Minnesota, and northeastern South Dakota. This region also extends into southern Canada. *Pothole* is defined as a surface depression occurring in glacial sediments, containing water from precipitation, surface runoff, and groundwater. Vegetation characteristics include cattails and various species of grasses, sedges, and rushes such as bulrushes. More ephemeral potholes are characterized by meadow grasses and sedges. Prairie potholes are shallow wetlands in a region that is fairly flat to rolling; they can occur at many different elevations. These saucer-shaped depressions have an average depth of about 2 to 5 feet (0.6 to 1.5 m). Their appearance is dependent on the size and shape of the original stagnant ice block that formed them and on the effects of wind-induced wave erosion. Individual potholes can range in size from a few hundred square yards up to several thousand square miles.

Potholes are not usually associated with any regional network of stream channels, but they are related to local and regional groundwater systems. Water input is from groundwater inflow (discharge), direct precipitation, and occasionally from surface inflow from excess stormwater or snowmelt runoff. The hydroperiods in wetlands range from temporarily to permanently flooded. These differences cause the development of diverse vegetation zones such as wet meadow, shallow marsh, and deep marsh. Prairie potholes lose water through evaporation, transpiration, and seepage to groundwater.

Prairie potholes are extremely important wetland resources in a region with few rivers, lakes, or other productive wetland types. Approximately 50 to 75 percent of all North American waterfowl use this region for breeding and for resting during migration. Other birds and mammals, such as blackbirds and deer, are also common to the pothole region. Drainage of these wetlands for commercial cropland production threatens them as limited water resources. Degradation of prairie potholes from stormwater discharges is a growing concern where potholes occur in urban or urbanizing areas.

Sand Hills Wetlands

The Sand Hills wetlands account for about 5 percent (1.3 million acres or 0.5 million hectares) of the Sand Hills area, which consists of central and eastern Nebraska and a portion of South Dakota. Fifteen percent (28,021 acres or 11,340 hectares) of the original wetlands were lost before 1970. These wetlands are a result of hilly topography in conjunction with permeable geologic formations. Small lakes, marshes, and wet meadows occur in the interdune areas. Approximately 194 species of grasses, sedges, rushes, floating leaved, and submerged plants, such as Japanese brome, spreading bentgrass, and fox-tail barley (Segelquist et al., 1990), dominate these wetlands. These wetlands are important migration sites for waterfowl, shorebirds, and songbirds. Approximately 80 percent of the Sand Hills wetlands are less than 10 acres in size. The following wetland types are typical:

- **Seasonally flooded basins** are flooded during spring and well drained the rest of the year.
- **Fresh (wet) meadows** have no standing water but have waterlogged soils and root zone during the growing season; vegetation consists of sedges and grasses.
- **Subirrigated meadows** have plant roots in contact with the water table.
- **Shallow fresh marshes** have waterlogged soils for most of the year; marsh areas have standing water and emergent aquatic vegetation.
- **Deep fresh marshes** have a flooding depth of up to 3 feet in spring and early summer.
- **Open freshwater lakes and ponds** are typically perched above local groundwater levels, or where topography is below the water table level; a small change in depth yields a large change in water area because of very shallow lakes. In the westernmost region of the Sand Hills, lakes and ponds are alkaline and have less diversity of wetland plant species.
- **Wind pump wetlands** are small wetlands caused by overflowing wind-powered pumps that tap underlying groundwater.

Most of the wetlands are influenced by local hydrogeology. There is negligible groundwater inflow from areas beyond the Sand Hills. Annual precipitation ranges from 16 inches in the west to 24 inches in the east, and is the principal source of water. Highly permeable soils and grassy dune vegetation promote high rates of water infiltration. Within the interdune valleys, the accumulation of fine sediments and organic material has reduced permeability Therefore, snowmelts and spring rains result in the wetland formations described previously. The hydrology of each wetland type is dependent on the rate of water input and the rate of downward infiltration. Other factors influencing groundwater recharge are soil characteristics, geology, and water table depth. These “subirrigated” meadows are unique because they have more consistent precipitation and infiltration rates than other wetland types with more seasonal variations and their water level is almost permanently at ground level. Many have a fairly constant hydrologic input from groundwater. This constant inflow continues even in drier years.

The Sand Hills wetlands are an integral part of the Sand Hills hydrologic system. The meadowlands have economic significance because of hay production, as well as ecological significance related to lakes and marshes. Although the wetlands themselves play a relatively minor role because they constitute only 5 percent of the land surface, the Sand Hills area is important for recharge of water to the underlying Ogallala High Plains aquifer, which extends into other portions of Nebraska, as well as parts of Kansas, Oklahoma, and Texas.

Peatlands of the North-central States

The peatlands of the north-central states include the Red Lakes Peatlands of northern Minnesota, one of the largest areas of peatlands in the country Peatlands in this area have low topographic relief and have a depth ranging from 3 to 10 feet. *Peatland* describes wetlands that have soils composed of partially decomposed remains of plants. The decomposition rate is low because of low oxygen concentrations and saturated soils. Bogs and fens are the predominant types of wetlands found in the peatlands of the north-central states.

Bogs have acidic, fibrous, spongy, nutrient-poor organic soil (phosphorus and potassium are the limiting factors), whose organic plant material consists mostly of sphagnum moss. Because of their location at or above the local groundwater table, bogs acquire most of their water from precipitation and primarily support the growth of acid-tolerant trees and shrubs such as the tamarack, the black spruce, and the leatherleaf. Fens represent a transitional stage between marshes and bogs. Fens obtain water not only directly from precipitation, but also by surface runoff and groundwater seepage. Fens support diverse plant communities consisting of sedges, grasses, reeds, and some woody vegetation. Both areas contain a vast number of invertebrates, insects, and amphibians.

Water chemistry determines the development of different wetland types. Acidic water with a very low mineral content is typical of bogs, while the fens are characterized by the reverse. These water chemistry differences are related to water origins. Mineralized fen water originates from groundwater, whereas precipitation produces the high-acidity, low-mineral water content of a bog.

Peatlands have a hydrogeologic flow system independent of regional groundwater movement. Some limited groundwater recharge might occur in the sandy former shorelines of glacial lakes, where more permeable sediments would permit the percolation of water. Some examples of particular groundwater interactions are spring fens and groundwater mounds. The former result from upward seepage of regional groundwater, and the latter are a result of the mounding of the water table. Also, because of increased elevation of water in groundwater mounds, a gradient is created, thereby resulting in a return of flow downward.

As a result of increased agricultural cultivation over the last 100 years, many of the peatlands in the north-central states have been drained. The increase in impervious surfaces that results from development associated with urbanization has the potential to adversely impact certain peatlands, particularly fens due to their receiving surface water flows.

Bottomland Hardwoods

Bottomland hardwoods are forested wetlands in the river valley floodplains of the Atlantic Coastal Plain (extending south from Virginia to Florida), and of the Gulf states of Alabama, Mississippi, and Louisiana. They occupy the broad floodplains, seldom exceeding a width of 5 miles. Since the settling of America, 60 to 80 percent of the original area of these wetlands has been lost. Bottomland hardwoods consist of flood-tolerant species of oak, gum, cypress, elm, and ash. These species are adapted for survival in areas that are flooded between 20 to 150 days a year. Vegetational characteristics are determined by the overall extent of seasonal flooding. This region is also home to a diverse number of animal and bird species such as deer, raccoons, owls, and hawks. Forested wetlands like the bottomland hardwoods are important wood duck breeding habitat.

This seasonal hydrology also affects surface water and groundwater movement. In drier seasons, floodwaters and lateral groundwater movement serve as the dominant inputs. Other input sources include overbank flooding from the main channel, flooding from small tributary streams, lateral overland flow from valley sides, lateral groundwater flow from valley-side rock formations, and movements of groundwater parallel to the main river channel. Where there are permeable rock formations in the local geology like limestone, groundwater helps maintain wetland characteristics through seepages and springs. Recharge can also occur in the form of bank storage. As water levels rise, water can move laterally from the channel to the adjacent floodplain.

During floods, bottomland hardwoods trap, filter, and attenuate inputs of sediments and nutrients. In instances of high rainfall conditions they filter upslope surface runoff. They can also provide continual recharge to the aquifer, raising groundwater levels up to hundreds of feet away from the channel.

Swamps and Bogs of the Northeast

Two wetland types common to the Northeast are swamps and bogs. Swamps and bogs occur in the Northeast in Pennsylvania, New Jersey, New York, and New England. Swamps consist of woody vegetation occurring on poorly drained lowlands. Generally, they are found in valleys and valley-side depressions that are periodically flooded. They are associated with surface drainage systems and periodically can have standing water. Their size ranges from small depressions of less than an acre to many acres. Northern floodplain swamps have an abundance of hardwoods. Other swamps, not bordering a river, may contain a mixture of evergreen and deciduous trees. Trees common to the areas are the white cedar and the red maple. Bogs are a type of wetland dominated by peat soils, which are nutrient-poor acidic soils dominated by sphagnum moss. Bogs can occur on flatland, on slopes, or as raised bogs as is the case in northern Maine. Bogs can support only hardy, acid-tolerant trees and shrubs, heath species, and sedges such as the black spruce, the tamarack, orchids, and insect-eating plants. Depending on the dominant vegetation, bogs can be described as forested, scrub-shrub, or moss-lichen types. Both areas in this region harbor animals and birds such as deer, rabbits, grouse, and owls. In addition, swamps and bogs are home to a diverse array of rare plants.

The hydrology of swamps and bogs differs greatly. Groundwater, floodwaters, and tidal innundations provide input to swamps, while rainfall provides hydrologic input to bogs. Swamps collect groundwater from valley-side seepage, from the soil of downslope depressions, and through fractures in bedrock. Discharge leaves the swamp as stream flow and/or seepage. Groundwater is not a major hydrologic component of bogs, although the water that bogs hold is considered groundwater. Bogs in the Northeast are hydrologically self-contained and are referred to as *ombotrophic;* there is little inflow or outflow of either surface water or groundwater. They are isolated from the high mineral content of groundwater and are therefore very acidic. Although water is not released to stream systems, it can be released as seepage during times of surplus precipitation. This lateral movement, however, is very slow.

The functions of both wetlands also vary Water stored in swamps attenuates the movement of water through the complex integrated hydrological systems involving groundwater, wetlands, rivers, and lakes. During storm flooding in a dry era, the flooding of a wetland serves as a recharge source to adjacent aquifers. Bogs, because they retain water so well, act as giant sponges and do not let much water leave as seepage. What little water is released does not necessarily increase dry stream flow or recharge aquifers.

Cypress Dome Wetlands

Cypress dome wetlands occur in southern Georgia and in the Florida wetlands. The term *cypress* dome, also referred to as “cypress pond” and ‘cypress head,” is defined as a hardwood forested wetland occurring in seasonally or permanently wet saucer-shaped depressions. These wetlands are small in scope, usually not exceeding 25 acres (10.1 hectares) and are dominated by pond cypress trees, some of which are over 400 years old. If enough light penetrates the canopy, understory vegetation like the wax myrtle can grow. Viewed from the side, these trees assume a characteristic dome-shaped profile, with the smaller trees toward the edges and the larger trees in the middle. The arrangement of the trees in this manner is due to the occurrence of wildfire, which often burns only the outer, smaller trees. These domes contain acidic water and organic soil that is thickest in the middle and thinner toward the edges of the domes. Snakes, alligators, and nine species of frogs are common in this region.

Cypress domes occur in flat areas where the water table is close to the surface; this surface water is connected to shallow aquifers. Movement of water from cypress domes proceeds in a lateral direction. Primary hydrologic inputs to cypress dome wetlands are rainfall and surface water inflow. Water is lost through evapotranspiration and seepage to groundwater systems. The deciduous leaves of cypress trees seasonally influence the water budget due to the changes in the amount of interception of rainfall and transpiration. In the summer months of maximum rainfall, a net inflow into the wetlands results. The reverse occurs during drier times, providing some recharge. Groundwater recharge/discharge is influenced by the geologic formation beneath the cypress domes. Cypress dome wetlands located above sinkholes can create permeable pathways between the wetland and the aquifer and are capable of recharging deeper limestone aquifers. Cypress dome wetlands have been used for the natural treatment of effluent.

Permafrost/Tundra Wetlands

Permafrost/Tundra wetlands are situated in the interior of Alaska and are the western extension of the wetland complexes of northern Canada. Severe frost is the most important characteristic that distinguishes the hydrology of these wetlands. Water is frozen in the ground year-round, resulting in impermeable layers known as permafrost. Permafrost encompasses over a half-million square miles in Alaska. This condition is continuous in the north, but scattered in regions farther south. Permafrost areas are very sensitive to minute changes in vegetation cover and drainage. For instance, color, thickness, and degree of saturation of the wetland determine the thermal properties of the wetland, which in turn determine summer thaw depth and winter freeze depth. Thawing occurs at a maximum of 3 feet, and freezing can extend up to hundreds of feet. Wetlands produced by permafrost are seasonal thaw ponds, shallow emergent wetlands, partially drained lake basins, and wetlands in wet and dry tundra. The term *muskeg* means peatland, and it constitutes the organic content of these wetlands. A brief summer growing season produces limited vegetation consisting of mosses, lichens, and sedges. Mosses fill a particularly important ecological niche because of their role in peat formation; the rate of which is about one inch per 300 years primarily due to the cold temperatures.

The water budget of the permafrost/tundra wetlands of Alaska varies from site to site. Precipitation in the Alaskan interior yields less than 12 inches (30.5 cm) per year. However, because of limited evapotranspiration, there is a net surplus of water available. Both snowmelt and rainfall are very important water sources for wetlands. Precipitation is the main water input because of impermeable conditions created by permafrost. Very little water is lost or received to or from stream and groundwater flow, although there are exceptions. Groundwater recharge can occur in certain instances where summer snowmelt and precipitation percolate through frozen, but dry surfaces, or on the warmer southern-facing slopes that have permafrost-free zones allowing for infiltration. In warmer areas where there is groundwater circulation, more mineralized water can emerge, resulting in the formation of arctic fenlands. Icings and icy mounds are wetland features that are the result of springs that continue to flow in early winter. The timing and amount of summer rain and snowmelt have a significant impact on the characteristics of individual wetland areas.

Stormwater Factors

Stormwater Quantity

Changes in land use within a watershed usually result in changes to stormwater runoff volume and quality. For example, urbanizing watersheds are characterized by increases in impervious surfaces, which include roads, sidewalks, parking lots, and buildings, as compared to rural land uses. Increased imperviousness leads to increased runoff volumes and velocities and higher pollutant loads. Moreover, natural stormwater conveyances tend to be replaced with hard structures such as concrete gutters or swales because of the increases in erosion that often accompany increased runoff amounts and velocities.

Runoff and Peak Flow

Land use changes alter the established rainfall-runoff relationship that exists in a watershed. The most common effects are reduced infiltration and subsequent reduction in the time of concentration (which is the time it takes surface runoff from the most distant point of a watershed to reach the first swale, gutter, sewer, or channel) (Maidment, 1993). Travel time, the time it takes flow to move through various conveyance elements to the next inlet or design point, may also be decreased by urbanization. Both of these factors can significantly increase peak discharges and runoff (USDA-SCS, 1986). Runoff volumes are primarily determined by the amount of precipitation and by the infiltration characteristics of an area. For a given location, some of the factors that determine infiltration characteristics are more likely to be influenced by human intervention than others. The amount and type of precipitation for a given location can be quite variable, but are not likely to be modified by human actions. The infiltration characteristics are a function of soil type, soil moisture, antecedent rainfall, cover type, impervious surfaces, and surface retention (USDA-SCS, 1986). Activities that increase imperviousness, decrease surface retention, or modify cover type can lead to increases in surface runoff or peak discharge.

As mentioned above, travel time is the time it takes runoff to travel from the point where sheetflow enters a recognizable conveyance element (e.g., culverts, swales, over land), through the various conveyance elements, to a specified point in a watershed (Urbonas and Roesner, 1993). Travel time is principally a function of slope, length of the flow path, depth of flow, and the roughness of the flow surfaces (USDA-SCS, 1986). As land uses in a watershed become smoother (e.g., imperviousness increases or forested areas decrease), the velocity of runoff increases, which decreases the travel time (Urbonas and Roesner, 1993).

Peak discharge changes are often good indicators of changes in land use within a watershed that will affect the hydrology of natural wetlands. The relationship between runoff volume, watershed drainage area, relative locations of urbanized areas, effectiveness of flood control structures or other storage, the time distribution of rainfall during a storm event, and travel time determines peak discharge (USDA-SCS, 1986). The estimation of peak flows on small (16.1 miles^2 or<25.9 km^2) to medium-sized (321.9 mile^2 or <518 km^2) watersheds is a very common application of stormwater runoff estimation (Pilgrim and Cordery, 1993).

Mathematical relationships, or models, are used to approximate the relationship of rainfall to runoff. The results from modeling approximations used to predict runoff from a particular area are generally much better at indicating changes in runoff, rather than absolute runoff volumes. For the purpose of determining impacts to wetlands from stormwater runoff, estimating relative changes in runoff volume and peak discharge is sufficient.

A variety of methods exist to determine runoff volume or peak discharge for sizing and designing conveyance systems and detention facilities. Pilgrim and Cordery (1993) and Maidment (1993) describe several different approaches for predicting runoff volume and peak discharge. Some of the modeling approaches focus on runoff and others on the loss, the part of the rainfall that does not run off. The assumptions of the different approaches are summarized below:

- Loss (and conversely runoff) is a constant fraction of rainfall in each time period, or for storms with constant rainfall intensity, a simple proportion of the total rainfall. An example method using these assumptions is the *rational formula.*
- Runoff is the residual after a selected constant loss rate or infiltration capacity is fulfilled. Examples include use of probable maximum flood computations and the prediction of hydraulic conductivity (assuming sufficient soils data are available).
- Initial loss and continuing constant loss rate index models are similar except that the initial runoff is zero until an initial loss capacity is met regardless of the rainfall rate; then runoff is a constant rate.
- Runoff is estimated by an equation that represents a function of the capacity rates of loss decreasing with time. The equations may be based on empirical relationships or physically based models. An example is the Green and Ampt (1911) equation.
- Runoff is represented by rainfall-runoff relationships, such as the U.S. Soil Conservation Service TR-55 method, a runoff curve (CN) method.

Rainfall

Rainfall and snowmelt are the basis for stormwater runoff and are variable in space and time. In the estimation of runoff or peak flows, rainfall is represented by a hyetograph, which is the time pattern of rainfall intensity When data are available, recorded rainfall can be used to determine the hyetograph, which may be assumed to be constant for the entire watershed if sufficient spatial data are not available. In the absence of sufficient local data, regional design rainfall of average intensity (found in national intensity-duration-frequency information) can be used (Pilgrim and Corder-y, 1993). National precipitation data are published in *Climatological Data andHourly Precipitation Data* by the National Climatic Data Center, which is part of the National Oceanic and Atmospheric Administration in the Department of Commerce.

Storm Frequency refers to the time between rainfall events of equal intensity (return periods). Storm (and flood) frequency can also be expressed as a probability For example, a 25-year frequency storm has a 4 percent chance of happening in any year. *Storm intensity* is typically defined as a volume of rain in a given time period, Maps are available that show rainfall for durations from 30 minutes to 24 hours and return periods of 1 to 100 years (Hershfield, 1961). The frequency and intensity of storm events vary regionally and seasonally. For example, storm events in the central and southwestern United States typically occur less frequently than those in the East, but may occasionally produce large volumes of runoff. Some areas may receive the bulk of their annual precipitation as snowfall, and snowmelt would be a major contributor to streamflow and runoff in such regions. In a summary of several studies related to urbanization in a watershed, the largest changes in runoff were associated with 2-year storm events, not l00-year events (Urbonas and Roesner, 1993).

Stormwater Quality

Runoff can be characterized by the use of the land from which the runoff comes. For example, the constituents of runoff from farmland are likely to be different from those in urban runoff. Agricultural runoff tends to be high in nitrogen, phosphorus, bacteria, and suspended sediments. The principal types of pollutants found in urban runoff include sediment, oxygen-demanding substances, nutrients (phosphorus and nitrogen), heavy metals, pesticides, hydrocarbons, increased temperature, and trash or debris (Woodward-Clyde Consultants, 1990).

The source of sediments in stormwater might be erosion of bare soil in the watershed or channel scouring due to increased stormwater volumes and velocities. Sediments in surface water may settle in wetlands because of the effects of wetland morphology and vegetation on the lowering of water velocities. Some wetland types, such as tidal and riverine wetlands, might benefit from settling of some sediments and particulates, while other wetland types might be adversely affected by even low sediment loadings. High sediment loadings might affect plant communities or reduce fish spawning habitats in a wetland (Canning, 1988).

Another effect of urbanization is generally higher runoff water temperatures in the summer and colder temperatures in the winter, primarily because of a reduction in vegetative cover and resulting rapid drainage (Galli and Debose, 1990). Higher summer water temperatures are associated with decreased dissolved oxygen levels in surface waters, which affect the aquatic faunal community

Pollutants found in stormwater runoff are not transported in the same form; for example, phosphorus and metals are primarily transported bound to sediments, and nitrogen is often a dissolved pollutant. Also, the levels of pollutants in runoff can vary according to season and land use in a watershed (Hickock et al., 1977). Urban wetlands can be affected by increased loadings of pollutants in runoff in comparison to predevelopment levels.

Wetlands that receive stormwater discharges with high sediment levels from sources such as uncontrolled construction sites can be impacted by excessive silt loads or altered flow patterns. Large flow volumes, high velocity, and long-term pollutant loads delivered by stormwater discharges can alter or destroy stable wetland ecosystems (USEPA, 1995).

The Nationwide Urban Runoff Program, or NURP (USEPA, 1983), although limited in scope and purpose, is still considered by the Agency to be the most comprehensive national assessment of pollutants in urban runoff. The major focus of NURP was to characterize the water quality of runoff from residential and commercial areas and from industrial park sites. The program evaluated data from 81 sites in 22 cities and covered more than 2,300 individual storm events. Because the industrial park category did not include heavy industrial activity, data from the industrial parks were merged with the data collected from the commercial areas. It should also be pointed out that the sites evaluated in NURP were selected in part for their low probability to be influenced by pollutant contributions from construction sites, heavy industrial activities, illicit connections, or other confounding influences.

The NURP study provides insight on what can be considered background levels of pollutants for runoff from residential and commercial land uses (USEPA, 1995). The majority of samples collected under NURP were analyzed for seven conventional pollutants (biochemical oxygen demand, chemical oxygen demand, total suspended solids, total Kjeldahl nitrogen (TKN), nitrate plus nitrite, total phosphorus, and soluble phosphorus) and three metals (total lead, total copper, and total zinc). Median values for the NURP pollutants are reported in Table 2-4, along with their corresponding coefficients of variation. The original NURP data presented in Table 2-4 are reported for four land uses: residential, mixed, commercial, and open space. Table 2-5 summarizes the event mean concentrations as composite results for the same four NURP land use categories.

Because the NURP sites represent average runoff conditions from a mix of residential, commercial, and industrial park sites, loading estimates based on NURP concentrations will be influenced by loadings from some of the sources considered in the industrial and commercial analysis that were located in the catchments monitored (USEPA, 1995). It is, therefore, important to consider the land use from which runoff originates, as well as other watershed-specific conditions, when evaluating BMPs to treat stormwater quality for protecting wetlands. Table 2-6 shows different types of land use, the pollutants expected in runoff from those land uses, and the potential effects of those pollutants on wetlands. This table can be used as a basis to start evaluating stormwater quality when determining potential impacts to wetlands.

Table 2-4. Results of the Nationwide Urban Runoff Program

Median Event Mean Concentrations for All Sites by Land Use Category

	Residential		Mixed		Commercial		Open/ Nonurban	
Pollutant	**Median**	**CV**	**Median**	**CV**	**Median**	CV	**Median**	CV
BOD (mg/L)	10.0	0.41	7.8	0.52	**9.3**	0.31	-	-
COD (mg/L)	73	0.55	65	0.58	57	0.39	40	0.78
TSS (mg/L)	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead (mg/L)	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper (mg/L)	33	0.99	27	1.32	29	0.81	-	-
Total Zinc (mg/L)	135	0.84	154	0.78	226	1.07	195	0.66
TKN (mg/L)	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrate plus Nitrite (mg/L)	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus (mg/L)	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus (mg/L)	143	0.46	56	0.75	80	0.71	26	2.11

Source: USEPA. 1983 Note: CV = coeffcient of variation.

Table 2-5. Summary of Event Mean concentrations from NURP for Selected Pollutants

Composite of All Land use ***Categories***

Constituent	*Mean*	*Median Site*	*90th Percentile Site*	*Coefficient of Variability for Event*
BOD (mg/L)	12	9	15	0.5-1
COD (mg/L)	94	65	140	0.5-1
TSS (mg/L)	239	100	300	4-2
Total Lead (mg/L)	0.24	0.14	0.35	0.5-1
Total Copper (mg/L)	0.05	0.03	0.09	0.5-1
Total Zinc (mg/L)	0.35	0.16	0.50	0.5-1
TKN (mg/L)	2.3	1.5	3.3	0.5-1
Nitrate plus Nitrite (mg/L)	0.86	0.68	1.75	0.5-1
Total Phosphorus (mg/L)	0.50	0.33	0.70	0.5-1
Soluble Phosphorus (mg/L)	0.15	0.12	0.21	0.5-1

Source: *USEPA, 1983, 1995.*

Table 2-6. Effects of Pollutants from Different Land Uses/Sources on Wetlands

Land Uses/Sources	*Typical Pollutants*	*Effect on Wetland*
Agricultural runoff (cattle) grazing land, manure)	Bacteria (coliform, streptococcus)	Contamination of shellfish, rendering them inedible
	Sediment	Clogged bottom sediments, interfering with fish spawning and benthic invertebrates
	Nutrients	Increased vegetative productivity, resulting in increased standing stocks of vegetation, followed by increased rates of vegetative decay and higher Community respiration rates
	Organic matter	Greater oxygen demand/depletion
	Pesticides, salts	Alteration of species distribution
Agricultural runoff feedlots)	Nitrogen, phosphorus	Increased vegetative productivity, resulting In increased standing stocks of vegetation followed by increased rates of vegetative decay and higher community respiration rates
Commercial stormwater runoff	Total nitrogen	Increased vegetative productivity resulting In increased standing stocks of vegetation, followed by Increased rates of vegetative decay and higher community respiration rates
	Heavy metals (Pb, Zn, Cu, Cd)	Alteration of Species distribution
	Petroleum residues	Decreased growth and respiration rates (Chronic toxicity)
Residential stormwater runoff **low to moderate density)**	Total nitrogen	Increased vegetative productivity, resulting In increased standing stocks of vegetation, followed by increased rates of vegetative decay and higher community respiration rates
	Bacteria (coliform)	Contamination of shellfish, rendering them Inedible
	Heavy metals (Pb, Zn, Cu, Cd)	Alteration of species distribution
	Petroleum residues	Decreased growth and respiration rates (chronic toxicity)
	Pesticildes (diazinon)	Alteration of specks distribution
Urban runoff (developing Areas)	Suspended solids	Clogged bottom sediments. Interfering with fish spawning and benthic Invertebrates (smothering)
	Nitrogen, phosphorus	Increased vegetative productivity, resulting In increased standing stocks of vegetation, followed by increased rates of vegetative decay and higher community respiration rates
	lead	Alteration of species distribution; decreased growth and respiration rates (chronic toxicity)
Highway **stormwater runoff**	BOD	Greater oxygen demand/depletion
	Sheet flow blockage by embankments	Sheet flow reduced by embankments, decreasing the sediment supply to wetlands and making the waters more likely to stagnate when fully flooded.

Table 2-6. (continued)

Land Use/Source	*Typical Pollutants*	*Effect on Wetlands*
Highway Stormwater runoff (cont.)		Alternation of me hydrologic regime, sediment loading, and direct wetlands removal; hydrologic isolation, decreased salinity in tidal marshes, and increase in vegetative cover; nutrient retention and signs of eutrophication
	Oil and grease; polyaromatic hydrocarbons	Reduced species diversity
	Heavy metals (Pb, Zn) and deicing salt/sand	Alteration of species distribution and replacement of sensitive species with tolerant species; Decreased growth and respiration rates (chronic toxicity)
Multifamily residential area Stormwater runoff	Nitrogen, Phosphorus	Increased vegetative Productivity. resulting in Increased standing stocks of Vegetation, followed by increased rates of vegetative decay and higher community respiration rates
	Suspended solids	Clogged bottom sediments, Interfering with fish spawning and benthic invertebrates (smothering)
	BOD	Greater oxygen demand/depletion
	Bacteria (coliform)	Contamination of shellfish, rendering them inedible
	Heavy metals Ku. Pb, Zn, NI, As, Be)	Reduced species diversity
	Organics (bls-2-ethylhexyl phthalate)	Replacement of sensitive species with tolerant species.
	Pesticides (a-BHC)	Alteration of species distribution
		Decreased growth and respiration rates (chronic toxicity)
Urban stormwater runoff (developed)	Nitrogen, phosphorus	Increased vegetative productivity, resulting in increased standing stocks of vegetation, followed by increased rates of vegetative decay and higher community respiration rates
	BOD	Greater oxygen demand/depletion
	Suspended solids	Clogged bottom sediments, interfering with fish spawning and benthic invertebrates
	Heavy metals (Pb, Zn, Cu, Cd)	Alteration of species distribution
Pasture stormwater runoff	Suspended solids	Clogged bottom sediments, interfering with fish spawning and benthic invertebrates (smothering)
Cultivated land stormwater runoff	Nitrogen	Increased vegetative Productivity, resulting in Increased standing stocks of vegetation, followed by increased rates of vegetative decay and higher community respiration rates
	Suspended solids	Clogged bottom sediments, interfering with fish spawning and benthic invertebrates
Industrial area runoff	Hydrocarbons	Reduced species diversity; replacement of sensitive species with tolerant species; alteration of species distribution; decreased growth and respiration rates (chronic toxicity)
	BOD	Greater oxygen demand/depletion
	COD	Greater oxygen demand/depletion
	Suspended solids	Clogged bottom sediments. Interfering with fish spawning and benthic invertebrates (smothering)

Sources: USEPA, 1983 1993, 1995.

Factors contributing to the variability of pollutant types and loadings from similar land uses could include the following (Driver and Tasker, 1988):

Physical and Land-Use Characteristics

- **Total contributing drainage area** - a factor in determining the amount of runoff
- **Percentage of total drainage area that is impervious** - a factor in determining the amount of rainwater that runs off as opposed to being absorbed into the ground
- **Percentage of total drainage area that is industrialized** - a factor in determining the types of constituents likely to be present in runoff
- **Percentage of total drainage area that is commercialized** - a factor in determining the types of constituents likely to be present in runoff
- **Percentage of total drainage area that is residential** - a factor in determining the types of constituents likely to be present in runoff
- **Percentage of total drainage area that is nonurban** - a factor in determining the types of constituents likely to be present in runoff
- **Population density** - a factor in determining the amount of pollution per unit area that might be expected
- **Stream** flow - an influence on the amount of likely dilution

Climatic Characteristics

- **Total storm rainfall** - a factor in determining the amount of rain available to run off
- **Duration of each storm** - a factor affecting the amount of rain running off balanced by the amount that can be retained in the ground or channeled into another water body in a given amount of time
- **2-year maximum daily precipitation** - a factor explaining the expected climatic pattern for a geographic area
- **Mean annual rainfall** - a factor in determining the amount of rain available to run off
- **Mean annual nitrogen load in precipitation** - a factor explaining some of the sources of pollution to wetlands
- **Mean annual January temperature** - a factor explaining the expected climatic pattern for a geographic area
- **Surface water hardness** - an influence on the toxicity of certain hazardous substances (Owe et al., 1982)

Pollutant loadings-nitrogen, phosphorus, sediment, and lead-from urban, agricultural, and open space land uses were evaluated and plotted to aid in the selection of stormwater BMPs. Figures 2-2 through 2-5 show the median, maximum, and minimum pollutant loadings reported for several locations around the United States. Although these figures cannot be used to replace a thorough evaluation of site-specific conditions, they can be used initially to screen BMPs to shorten a list of potential BMPs to protect a wetland. For example, a wetland that is downstream from a predominantly urban area could potentially need to be treated for lead, whereas if the predominant land use were forest, lead would presumably not be a problem. Sediment loadings would be an important consideration for all land uses, but loading rates can vary widely within a land use category. The above-mentioned factors could account for the ranges of pollution from different land uses and from within the same land use category, as shown in Figures 2-2 through 2-5.

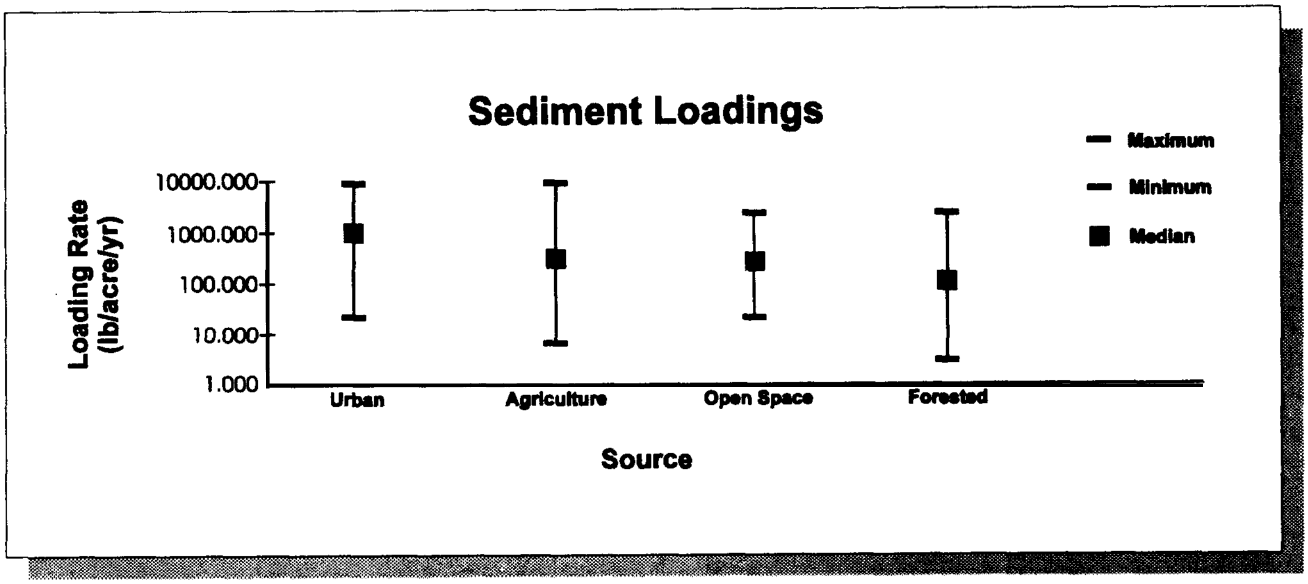

Figure 2-2. Sediment loading rates for various land uses.

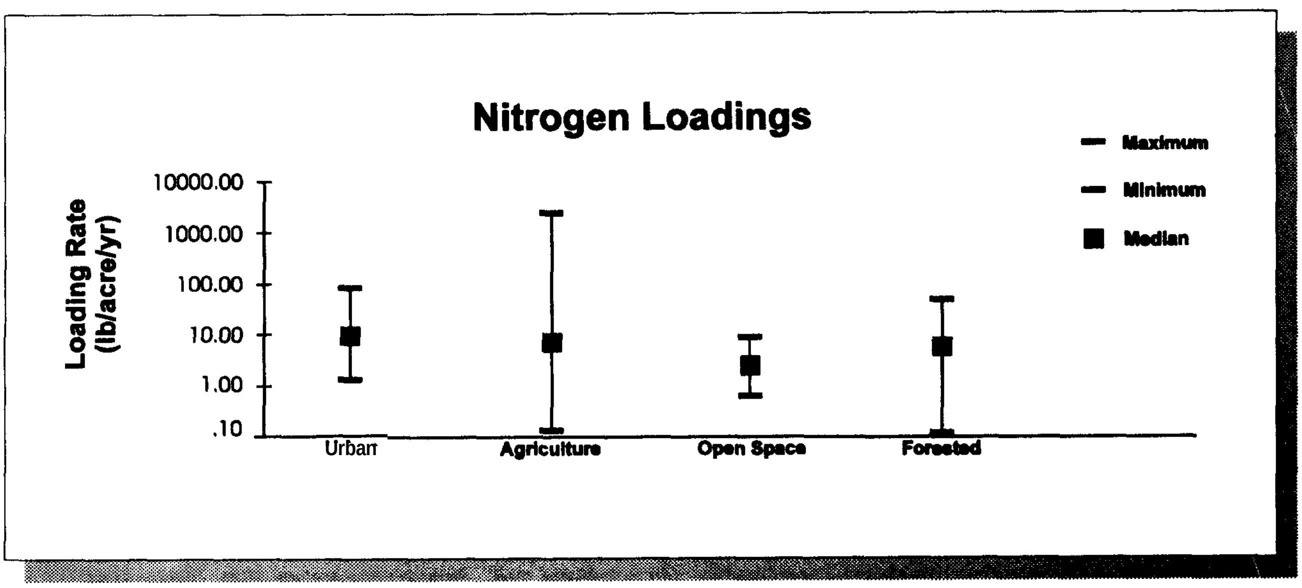

Figure 2-3. Nitrogen loading rates for various land uses.

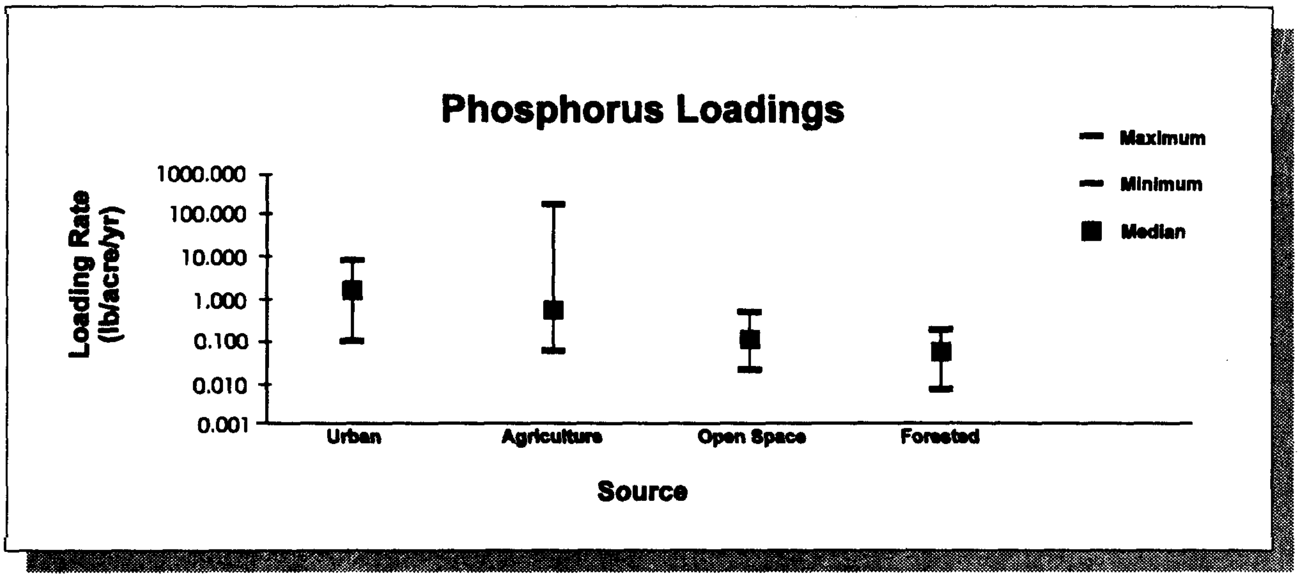

Figure 2-4. Phosphorus loading rates for various land uses.

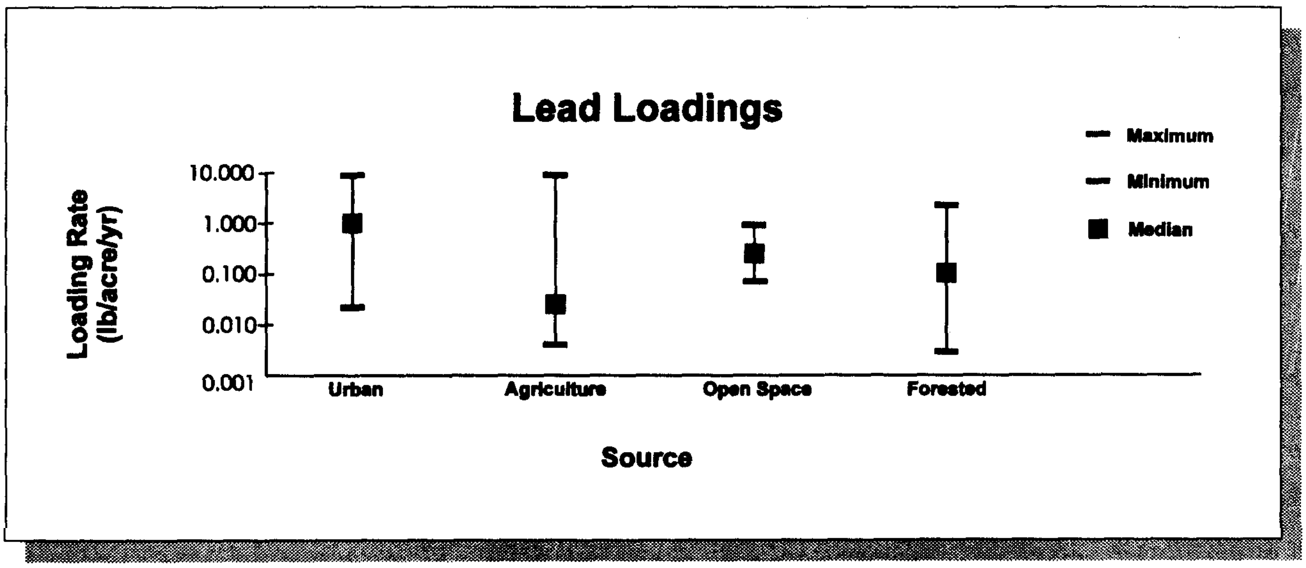

Figure 2-5. Lead loading rates for various land uses.

Sources for Figures for 2-2 through 2-5: Novotny *and Chesters, 1981: Shahane, 1982; Sweeten and Melvin. 1985; USEPA 1983.*

Overview of BMP Capabilities

Assessing the Ability of a BMP to Protect a Wetland

Wetlands can provide water quality benefits that should be considered when developing or implementing watershed planning. However, because natural wetlands are waters of the United States they must be afforded the same protection from degradation as any other receiving water. The wide variability of wetland types and the range of potential impacts from runoff make it very difficult to recommend a particular methodology to protect wetlands. EPA believes, however, that the use of natural wetlands for control of runoff should be avoided.

Different wetland types vary in their ability to handle the changes caused by stormwater flows and pollutant levels. Where runoff is specifically channeled or routed to wetlands, BMPs should be implemented to maintain the natural functions of the wetland. This might require the use of BMPs for water quality improvement, techniques to minimize changes in the natural hydrology of a system, or both. The principal question to be answered is whether the BMP is providing the level of protection necessary to ensure that the wetland retains its natural health and functions. Therefore, unlike other manuals that use end-of-pipe approaches, this manual focuses attention on the resource. To the resource manager this approach could be viewed by standing in the wetlands.

A variety of physical, chemical, morphological, and biological wetland functions could serve as appropriate indicators of the wetland's continued health and sustainability. These include:

- Groundwater quality and recharge
- Groundwater discharge
- Flood flow alteration
- Shoreline stabilization
- Sediment/toxicant retention
- Nutrient uptake, transformation, and removal
- Vegetative diversity, biomass production, and export
- Aquatic diversity and abundance
- Terrestrial wildlife diversity and abundance for breeding, migration, and wintering
- Stable recreational opportunity, uniqueness, heritage

The wetland's continued function and sustainability should be assessed. If it can be determined that the wetland is healthy, this might also be an indication that the proper BMP has been selected, has been well designed for the site and specific application, and has been well maintained (assuming other objectives of the BMP are being achieved, such as water quality). If there is some problem with the wetland (i.e., its function, health, or sustainability), the cause of the problem should be evaluated. Any combination of a number of causal factors could be responsible for the problem. These include, among others, choice of BMP, design, operation, and maintenance.

The evaluation should follow a logical, decision-tree-type sequence, working in reverse order (selection, design, operation, and maintenance). For example, if the improper BMP was selected for the site, none of the other factors would be likely to solve the problem, although they might help to some degree. Or, it might be determined that the proper BMP was selected but the design was not tailored to the site conditions (i.e., considering stormwater discharge factors and wetland factors like hydrology, soils, and vegetation). In other cases, an operational flaw might be altering the wetland's hydrology, or perhaps the BMP is not being maintained in the manner best suited to ensuring the continued health and function of the wetland.

It is likely that the same decision makers and technical personnel will be responsible for implementing both stormwater BMPs that discharge to wetlands and BMPs that do not discharge to wetlands. Therefore, these considerations should be emphasized to the appropriate staff so that the aspects of stormwater BMP selection, design, operation, and maintenance unique to practices used to protect wetlands are not inadvertently disregarded.

Although a number of manuals describe BMPs to be used to address stormwater runoff, this manual is a first attempt at addressing the specific water quality concerns related to wetlands. It is intended for use by anyone addressing potential impacts to wetlands from stormwater runoff, and it presents a wide range of planning approaches as well as specific BMPs that can be employed in a variety of situations. Although these are all discussed as BMPs for the purposes of this manual, some approaches might be more relevant and useful for large-scale planning efforts, whereas others are more appropriate for very specific localized problems.

Nonstructural Controls

Nonstructural controls are techniques used to manage stormwater runoff that do not require physical alteration of the land (USEPA, 1993). The prevention and minimization of pollutant loadings through source reduction and watershed planning are preferred over treating the unavoidable loadings that occur following urbanization. Watershed planning can help to reduce the need for expensive construction and maintenance of permanent structures if development in the watershed is accomplished in an environmentally sensitive manner that minimizes impacts. Obviously, opportunities for watershed planning will be limited by the current level and pace of development in a given watershed.

Nonstructural control practices applicable to wetlands include:

- Pollution prevention
- Watershed planning
- Advance identification of wetlands
- Permitting programs
- Preventive construction techniques (minimal impact development)
- Retaining open spaces, vegetated natural buffers, and riparian areas
- Inspection and maintenance of existing stormwater and erosion controls
- Education programs

Watershed Planning

Watershed planning involves the development of a watershed management plan, often as part of a comprehensive plan, The watershed management plan that describes existing patterns of environmental quality and community life in a watershed (including demographic trends, housing, infrastructure, economic activity, natural resources, and wildlife) and recommends goals and policies (including protection of drinking water sources and control of land uses) to manage future development to minimize impacts on water resources. A watershed management plan consists of maps of the watershed and its resources and text that explicitly addresses conflicts and trade-offs among development, environmental protection, social issues like as affordable housing, transportation, and many other factors. Watershed management plans also consider alternative actions and methods of measuring progress (CTIC, n.d.). Special-purpose planning, e.g., wetlands management planning, is one component of a watershed plan (USEPA, 1992c). Other components are wellhead protection and Class V (underground injection) well management.

Resource inventory and information analysis provide the basis of watershed management planning. For a plan to be effective, it should have measurable goals describing desired outcomes; for example, “Reduce loads to wetlands and surface waters by 25 percent.” The process of developing a watershed plan should also identify how wetland protection goals and other concerns of the plan will be addressed, and should identify information gaps. Coal setting must then be followed by developing means of measuring progress. For example, sediment input and specific pollutant loads can be assessed to determine whether the plan is being successfully implemented.

Watershed planning also allows stormwater managers to determine how best to control the quality and quantity of surface waters within a watershed after development has commenced. Ideally, this process will attempt to replicate, to the extent possible, the predeveloped hydrology of the watershed, including how wetlands function for flood storage as well as their water quality functions. Watershed planning is an opportunity for wetland managers to assess wetland protection needs, develop wetland restoration goals, plan mitigation strategies, and determine impacts from land use changes to wetland resources. When wetland resources are identified on a watershed (or landscape) scale, factors such as location of individual wetlands with respect to other wetlands, adjacent land uses, or water bodies can be factored into the decision-making process of a wetland resource assessment and the design of appropriate controls (structural or nonstructural) for preventing or treating stormwater discharges to natural wetlands.

Some increase in impervious surfaces, resulting hydrological changes, and a related addition of pollutant sources are inevitable results of urban and suburban development. BMPs attempt to mitigate these hydrological modifications and pollutant inputs. Without BMPs, wetlands receiving flows of uncontrolled runoff would likely become severely degraded. Therefore, the changes in hydrology rather than the BMPs are the cause of the problem. Nonetheless, where wetlands occur within a watershed, planning for BMPs needs to consider the impact of each BMP on wetlands and related groundwater resources.

A modeling mechanism may be incorporated into the watershed management plan. Such a model shows the cause-and-effect relationships within a watershed and can be used to test various land use/stormwater control scenarios to determine which option best preserves overall wetland functions or improves the health of a degraded wetland system.

The Maryland Nontidal Wetlands Program calls for watershed management plans that contain, at a minimum, a functional assessment of nontidal wetlands within a watershed; the location of potential mitigation sites; and plans for the protection of nontidal wetlands, limiting cumulative impacts, water supply management, and flood management (MDDNR, 1991). An effective wetlands watershed management plan may also include wetlands and floodplain protection ordinances, river corridor programs, sewer overflow provisions and siting controls, control of septic systems, requirements for pumpout stations for small boats, designing and siting of wastewater treatment facilities, surface water and groundwater quality controls; and non-point source pollution controls (USEPA, 1992c).

Once wetland resources and existing land use designations have been identified and the goals for wetland protection have been determined, implementation strategies can be developed to guide activities in the watershed. Nonstructural control practices (as opposed to structural practices) are the preferred technique for protecting wetlands because they are based on pollution prevention and reduction. Nonstructural control practices can be used within four program areas: permitted uses, preventive construction techniques, operation and maintenance, and education.

Permitting Programs

The goals of a watershed management plan, such as wetland protection and water quality improvement, can be implemented through various permitting programs such as land-use planning and zoning, natural resource/wetland protection ordinances, stormwater permitting programs, and other pollution control programs. Land development regulations may also require natural performance standards such as limiting rates of runoff, soil loss, or pollutant loadings into wetlands and the completion of environmental impact assessment statements prior to construction plan approval.

Preventive Construction Techniques

Stormwater quality and wetland protection can be improved through the implementation of numerous nonstructural preventive construction techniques for new development and redevelopment that help to minimize impacts, such as:

- Limiting the amount of impervious surface
- Requiring setbacks from wetlands, riparian areas, and surface waters
- Preservation of natural vegetation
- Open space requirements and slope restrictions
- Siting infrastructure so as not to adversely affect wetland and water resources
- Discouraging development in environmentally sensitive areas that are critical to maintaining water quality
- Site plan review procedures
- Performance standards for stormwater and wetlands

Operation and Maintenance

Maintenance of existing stormwater controls ensures continuing operation, effective pollutant removal, and the protection of wetland and surface water resources. Maintenance, such as the removal of sediments from detention and infiltration devices, the replanting of vegetation as upkeep within buffer and open space areas, and the maintenance of erosion and sediment control structures, is essential to the success of most structural and vegetation-dependent NPS pollution controls. Maintenance programs should require the prior designation of an entity or individual who is responsible for maintenance, and should stipulate the funding source or sources.

Outreach and Education Programs

Outreach programs can be designed to reduce individual contributions to stormwater problems and improve program implementation by maintenance personnel and government officials. Training programs and educational materials for public officials, contractors, and the public are also crucial to implementing effective urban runoff management programs. Contractor certification, inspector training, and competent design review staff are important to the success of a stormwater management program. The states of New Jersey, Virginia, Maryland, Washington, Delaware, and Illinois; NRCS; and the city of Alexandria, Virginia, have developed manuals and training materials to assist in implementation of urban runoff requirements and regulations (USEPA, 1993).

Education programs should be implemented in homes, in residential communities, and at the workplace. At a minimum, they should educate and encourage the public to participate in and support local pollution prevention programs. Such programs might include storm drain stenciling, used oil and hazardous chemical recycling, litter control, street sweeping, lawn management and landscaping, safe use and disposal of household hazardous materials and chemicals, correct operation of onsite disposal systems, including the danger of industrial wastewater discharges to septic systems, proper disposal of pet excrement, and water conservation.

Structural Controls

Structural controls are methods for managing stormwater that involve altering the flow, velocity, duration, and other characteristics of runoff by physical means (USEPA, 1993). Structural controls can be used for both stormwater volume control and water quality improvement. A fundamental consideration for design or selection of a particular BMP is whether the wetland hydrology is dependent on surface water flow, groundwater flow, or some combination of the two. Most structural controls are engineered structures that require regular maintenance. Structural controls that can commonly be used to protect wetlands include:

- Infiltration basins
- Infiltration trenches
- Sand filters
- Level spreaders (may be associated with gabions)
- French drains
- Grassed swales
- Vegetated filter strips
- Open spaces
- Extended detention dry basins
- Wet ponds
- Constructed wetlands

Less common controls may be used in special situations and for special purposes, usually to improve stormwater quality. These controls generally have limitations regarding applicability and maintenance. For example, untreated stormwater directed to a separator, dry well, or other shallow disposal system will eventually find its way to a water-table aquifer. Examples of these less commonly used controls include:

- Porous pavement and concrete grid pavement
- Oil/grit separators or water quality inlets
- Dry wells or roof downspout systems
- Exfiltration trenches

BMPs in Series

BMPs in series incorporate several stormwater treatment mechanisms in a sequence to enhance the treatment of runoff where determined necessary. By combining treatment mechanisms in series rather than using a single method of treatment for stormwater runoff, the overall levels and relability of pollutant removal can be improved. Some examples of serial BMPs include the use of multiple pond systems, the combination of vegetated filter strips with grassed swales and detention ponds, and the combination of grassed swales or vegetated filter strips with infiltration trenches. (For more information, see the fact sheet “BMPs in Series” in Section 4 of this manual.)

BMP Maintenance Requirements

When properly designed and located, BMPs can protect wetlands by providing preliminary treatment of stormwater to (1) restore or maintain predevelopment hydrology and hydroperiod by providing a balance between infiltration and detention or retention, (2) reduce fluctuations in nutrient levels, and (3) remove excessive levels of nutrients and sediments. The ability of stormwater pretreatment systems to provide these functions depends on both the effectiveness and reliability of individual BMPs or BMPs in series. Regular inspections and maintenance are essential to good performance for all BMPs (Washington State Department of Ecology, 1991). Failure to provide proper maintenance can result in reductions in the pollutant removal efficiency or reductions in hydraulic capacity of stormwater treatment systems (Washington State Department of Ecology, 1992).

If stormwater BMPs are not functioning properly due to inadequate maintenance, the result can be flooding problems and in some cases even an increase in the pollutant load of stormwater discharges (Washington State Department of Ecology, 1992). Effective maintenance can be ensured by clearly defining maintenance responsibilities and performing regular inspections to determine maintenance needs (Washington State Department of Ecology, 1992). Apart from achieving the required effectiveness and reliability, BMP maintenance and longevity are important considerations in the selection of a BMP not only because longevity varies considerably between treatment options, but also because maintenance costs may be high, in some cases rivaling construction costs over the design life of the BMP (Schueler et al., 1992).

Maintenance and maintenance costs can be reduced if maintenance needs are anticipated in the design stage (Schueler, 1987). The need for incorporation of maintenance provisions in facility designs is especially important when anticipating removal of sediment and debris from basins. Two specifics to be incorporated into site plans are access for maintenance equipment and easements. Easements are necessary around the perimeter of stormwater facilities to allow for maintenance and to provide a buffer from encroachment (Washington State Department of Ecology, 1992).

Maintenance is necessary to ensure that the storage and infiltrative capacity of the BMP is not compromised so that the BMP can effectively buffer wetlands from the detrimental effects of stormwater. The temporary storage and infiltration functions of pretreating stormwater can be partially accommodated by the wetland if not provided by the BMP, but not without potential damage to the wetland. Furthermore, stormwater might not be sufficiently treated before it enters the wetland. Regular maintenance is used to ensure that the BMP continues to function according to design specifications. Specific design variables that regular maintenance is intended to maintain include the detention time of pond systems; the flow path of stormwater to, from, and within the BMP (preventing erosion); the water level; and vegetative cover in and surrounding the device. Frequent problems that maintenance is targeted to address include clogging of infiltrative surfaces; blockage of inlet or outlet structures by debris; erosion of pilot channels, side slopes, embankments, and emergency spillways; sedimentation; accumulation of pollutants; overgrown or patchy vegetation; and nuisance insects.

The major mechanism by which pollutants are removed by BMPs is through sedimentation of sediment particles and pollutants attached to sediments. The more efficient a BMP is at removing sediments, the more frequently sediments and pollutants that have accumulated in the treatment device will need to be removed to ensure that the system continues to function properly (Washington State Department of Ecology, 1992). It is beneficial not to allow sediments to stand in the system for long because the longer the wastes accumulate in the system the more likely they are to become contaminated to the point where they might no longer be accepted for disposal at a landfill (Washington State Department of Ecology, 1992). Frequent sediment removal from catch basins, detention vaults, pretreatment inlets, oil/grit separators, vegetative BMPs, and pond forebays prevents sediments from being scoured by storms, which could result in shock loadings to receiving waters or clogging of a downstream BMP if BMPs occur in series. Pond systems require less frequent sediment removal; however, flooding can result if pond capacity is reduced by accumulated sediment. Infiltration devices that become clogged with sediment can also cause flooding.

Maintenance Factors

The degree and type of maintenance required depend on the BMP type, design, management objectives, climate, and surrounding land use. For instance, infiltration BMPs, although effective in removing pollutants, are usually less reliable than other types of BMPs due to poor longevity (Schueler et al., 1992). Specific management requirements for each of the stormwater pretreatment systems described in this document are provided in Section 4.

The type of maintenance depends on management objectives. For instance, pond systems composed of wet meadow or wetland marsh and constructed stormwater wetlands, adjacent to natural wetlands, may be managed for the dual purpose of promoting wildlife habitat and removing pollutants. Creation of wetland habitat within a stormwater treatment pond is especially important in areas where the value of natural wetlands has been diminished by construction of stormwater treatment systems adjacent to or in natural wetlands (South Carolina Coastal Council, 1988). Benefits of wetland creation include removal of soluble pollutants, provision of wildlife habitat, and disguise of unsightly debris and sediment deposits (Schueler, 1987). When a constructed wetland is placed adjacent to a natural wetland, the two wetlands form an integrated system, the function of which is significantly influenced by the management of the constructed wetland (DeVoe and Baughman, 1986). Management for waterfowl, the most common natural habitat objective, may employ some combination of water level manipulation, bed disturbance, and salinity manipulation in coastal areas. The goal of these practices is to promote the growth of aquatic plants that attract migrating waterfowl. The degree and timing of exchange of water between adjacent creeks, the constructed wetland, and the natural wetland influence dissolved oxygen, temperature, and aquatic species (such as fish and crayfish) recruitment (DeVoe and Baughman, 1986). Usually water levels of ponds and wetlands exclusively managed for waterfowl are maintained in the spring and fall for waterfowl migration. During the late spring, water is drained so the beds can be plowed in June. In October, the beds are flooded again (DeVoe and Baughman, 1986). There might be conflict of use between the need to maintain low water levels to capture stormwater and the need to maintain higher water levels to attract waterfowl. In addition, an objective might be to discourage waterfowl from using the constructed wetland if pollutant concentrations are expected to be high.

Mosquito control and frequent mowing will not be as important in an area managed for wildlife as in a residential neighborhood. Mosquitoes are a problem in wet meadows because rainfall pools in areas, allowing mosquito eggs to develop and hatch. Constructed wetlands and pond systems can be managed to minimize the production of mosquitoes by maintaining a system of ditches or canals for drainage. An aquatic weed control program can control mosquitoes by preventing an overgrowth of vegetation in the pond. Fish stocks can be maintained in the permanent pool of retention ponds (South Carolina Coastal Council, 1988). A pond that is scheduled to be filled for waterfowl use can be filled and emptied first to flush out resident mosquito populations (DeVoe and Baughman, 1986).

Implementation

Frequently, more attention is placed on design and location of structures than on maintenance. In addition, many jurisdictions do not have required BMP maintenance programs to ensure the adequate performance of BMPs (Schueler et al., 1992). The lack of routine inspection and maintenance is especially evident in the case of small, privately owned local disposal facilities, such as grassed swales, infiltration trenches, and infiltration basins, that are too small to justify a full-time staff person. The long-term effectiveness and reliability of BMPs can be enhanced through implementation of a maintenance and operation schedule for each BMP that explains routine and nonroutine maintenance tasks and identifies the party (or parties) responsible for performing them (Washington State Department of Ecology 1991). A maintenance plan developed for the life of the stormwater treatment facility can be required before the certification of a project (South Carolina Coastal Council, 1988). Inspectors need to be trained to know how the stormwater treatment system is designed to function and what the early warning signs of problems are. In addition to the brief overview of maintenance requirements of various types of BMPs, specific information is provided in Section 4 for each BMP to assist managers in developing their operation and maintenance plans.

Development of an Effective Maintenance Plan

Development of an effective maintenance plan requires site-specific information and a considerable amount of planning and foresight, beginning with the establishment of broad goals and objectives and ending with the scheduling of staff and equipment. Activities involved in designing an effective maintenance program include developing goals, reviewing existing policies, assigning responsibilities, planning the frequency of inspections, scheduling inspections, determining staffing needs, and determining enforcement procedures (Washington State Department of Ecology, 1992). Each component of the planning phase is discussed separately.

An effective maintenance plan reflects the specific priorities and goals of the community served by the stormwater treatment program, as well as watershed characteristics and existing policies within the jurisdiction (Washington State Department of Ecology, 1992). Therefore, development of a management plan begins with arriving at policies that outline who should be responsible for maintaining BMPs on private and public lands and how these policies will be enforced. The goal-setting stage differs from the final stages of maintenance plan development in that here utility officials should not constrain themselves to consideration of goals limited by current practices and policies but rather should consider how maintenance ideally should be performed, looking beyond the next 5 to 10 years to anticipate how decisions made now will affect future courses of action and alternatives (Washington State Department of Ecology, 1992).

Existing policies within a jurisdiction can either facilitate or impede an effective maintenance program. Once the goals of the maintenance program are identified, managers should review existing statutes, ordinances, and policies to assess how these complement the established goals of the maintenance program. In this manner, options for revising these policies where shortfalls are uncovered can be identified early (Washington State Department of Ecology, 1992). Design requirements for maintenance (e.g., access, clean-out traps, sediment disposal areas) should be included in ordinances and policies.

During the planning stage of the maintenance plan, staffing needs and limitations should be considered prior to deciding who will be responsible for performing maintenance tasks, specifically whether they will be performed privately or by the local government. Some distinctions may be made between routine and nonroutine maintenance activities or between facilities located on rights-of-way and those on private lands. If private individuals or organizations will perform the maintenance, an ordinance that requires owners to be informed of operation and maintenance frequency, schedules, procedures, responsibilities, and enforcement will be necessary For example, an ordinance might require that new owners be notified at the time of sale that they are owners of a stormwater treatment device and that they be provided with the operation and maintenance instructions (Urbonas and Stahre, 1993). An ordinance might not be required if local government will perform the bulk of the maintenance. If an ordinance is not used to assign responsibilities, consideration should be given to staffing needs and limitations, merits of alternative funding mechanisms, provisions for intergovernment cooperation, and specific needs or limitations (Washington State Department of Ecology, 1992).

Maintenance inspections need to be planned, including inspection frequency, scheduling, and staffing needs. In general, BMPs should be inspected and maintained once a year, at the very least, to remove debris, sediment, and vegetation that threaten the function or capacity of the facility and to replant damaged vegetation on grassed swales, vegetated filters, and buffer strips (Washington State Department of Ecology, 1992). The frequency of inspection depends on the age of the stormwater BMP, the occurrence of large runoff events that could damage the BMP, the history of problems encountered, and whether inspectors will perform routine maintenance.

Real estate transfer taxes are assessed as a percentage of property values when property is sold. These taxes are imposed on property buyers, sellers, or both. Funds raised by such taxes can be dedicated to help purchase environmentally sensitive lands or to support resource conservation programs.

> The Prince William County, Virginia, watershed management study is a project that is attempting to develop an innovative stormwater management plan through the use of BMPs and the restoration of riparian habitats. A 5-year, multimillion-dollar program to study the three urban Water-sheds is being funded through a federal-state-local cost-sharing approach. The Prince William County government Is funding 50 to 60 percent of the entire project. The remainder of the funding is being provided by the U.S. Fish and Wildlife Service, the U.S. Geological Survey, the Army Corps of Engineers. and the Environmental Protection Agency. The Prince William County government is helping to fund the project through a stormwater utility fee. Utility taxes can be imposed on property owners based on a variety of factors, such as the amount of runoff generated on a piece of property. (The fee can be calculated by the percent of the property that Is impervious.) Impact fees are usually collected at one time and can based on factors such as new land development.
>
> (See case study on P. 3-11 for more information.)

Commodity taxes are charged on specific items (commodities) such as gasoline, liquor, or cigarettes. The money raised could be targeted for environmental programs or services. A tobacco tax helps finance Washington State's water quality protection plan.

Tax surcharges are fees added to established tax rates. They are often used for sudden unforeseen events. A tax surcharge on residential sewer bills, for instance, might be used to finance the replacement of stormwater retention basins destroyed during a hurricane.

Stormwater utility taxes are imposed on property owners to pay for stormwater treatment. The charge can be based on the amount of runoff generated from the property, the amount of impervious area (hard surfaces) on the property, or the assessed value of the property There are more than 100 stormwater utilities in the United States. Methods of determining stormwater utility charges vary considerably around the country, depending on local stormwater management goals and conditions. In general, utilities are either publicly owned and operated enterprises or privately owned enterprises whose ability to profit from providing public services is regulated by a public agency. Utilities provide a more reliable source of funds for local stormwater management than do property taxes.

Tax incentives and disincentives refer to a tax system set up to encourage or discourage certain behaviors by offering tax reductions or increases. Incentives often take the form of state tax credits, deductions, or rebates. A tax credit for the use of low-flow plumbing fixtures, for example, can encourage water efficiency. Disincentives often take the form of fees, taxes, or price increases. A tax or fee, for example, can discourage the inefficient use of a product.

Fees

User fees are the most common way of recovering the costs of providing a service. These fees can tie directly to the users of a resource or facility (sportfishing license fees, for example). User fees are particularly useful at the local level, where user groups are easily identified.

An innovative example of a user fee is the State of Maryland's license plate program to fund its Chesapeake Bay Trust. More than 40,000 "Treasure the Chesapeake" license plates have been sold, raising over $4 million. Baltimore, Maryland, area Ford dealers offered Bay license plates at no cost to their new car and truck owners by paying the $10 fee from June through July 1991, raising $20,000 for the Trust.

Plan review fees are assessed by a local government to conduct a review of development plans to ensure that they meet certain requirements. This technical review includes determining the adequacy of stormwater management facilities, setback requirements, and wetland protection. These fees help cover the cost of conducting plan reviews and inspections.

Onsite inspection fees are charged to cover the costs of activities to make sure that development plans are properly implemented. These activities can include erosion and sediment control; BMP siting, implementation, and maintenance; and wetland protection. This approach defrays the cost of conducting inspections.

Impact fees transfer the costs of infrastructure services (roads, sewers, stormwater treatment) needed for private development directly to developers or property owners. Unlike user fees, which recover costs over the life of a project, impact fees are usually collected in one lump sum at the beginning of a project. These fees are particularly attractive to local governments because they relieve up-front financing pressures on local budgets. In California, for example, several wastewater treatment plants have been financed with fees paid by developers on the basis of the demands for treatment that their projects are expected to generate. Impact fees could be used for building regional stormwater management facilities.

The myriad programs that have been established to preserve and restore wetlands in the Chesapeake Bay watershed are an example of a multi-stakeholder federal, state, local, and private citizen partnership. Private organizations and public agencies, such as the Chesapeake Bay Foundation and the Environmental Protection Agency and the states of Pennsylvania, Maryland, and Virginia, are, in certain instances, pooling their resources to fund projects and create policies regarding the Chesapeake Bay watershed. For example, the Sea Grant College Chesapeake Bay Studies Program, which researches fish stocks, fate and transport of toxic pollutants, and remote sensing, is funded through a research grant from the National Oceanic and Atmospheric Administration. Remote sensing has been used successfully for identifying wetlands and dellneating the wetland/upland boundaries in the Chesapeake Bay region.

The state governments of Maryland and Virginia have implemented license Plate programs that provide part of the proceeds of the plates to a Chesapeake Bay Trust. Private citizen associations, such as the Herring Run Watershed Association in the Baltimore, Maryland, area can also receive funding from beyond their local membership. The Herring Run restoration project is a community. state, and federal partnership that Includes school curricula for 'adopting' and inventorying land use, planting trees, and caring for the existing forest buffers. The Maryland Department of Natural Resources recently accepted a grant of $22,300 from the U.S. Forest Service's Chesapeake Bay Program to help fund this effort to improve conditions within the Herring Run watershed.

Capacity Credits

Capacity credits are a form of financing in which private interests (usually developers) purchase future capacity in a public facility such as a stormwater treatment facility Applicants are guaranteed future access to the additional capacity of that particular facility When enough credits have been sold, work on the project begins.

Fee-in-Lieu

Fee-in-lieu is a method of easing environmental impacts on a regional or watershed basis. If a county or municipality determines that wetland restoration is too costly for an individual site, a fee can be charged to the property owner in lieu of implementing the restoration. The funds collected could be used to restore a more valuable wetland elsewhere in the watershed.

Bonds/Debt Financing

Bonds or debt financing raises up-front capital and distributes the burden of repayment for capital projects over the life span of the project and among those who benefit from it. Typically, bonds can be used only to finance projects that have both known and proven life expectancies. Short-term bonds are usually payable within 1 year. Establishing short-term debt provides interim funding of projects waiting to receive long-term financing. Long-term bonds traditionally match the term of financing with the life expectancy of the project. A stormwater treatment facility, for example, might be expected to perform adequately for 30 years; therefore, the community could issue up to a 30-year bond.

State Revolving Funds

State Revolving Funds (SRFs), which have been established since the Clean Water Act Amendments of 1987 by grants from EPA and state matching funds, can provide states with funds to finance NPS projects. They are generally operated by the state and provide long-term, low-interest loans to localities for major capital investments, such as stormwater retrofit projects. SRFs may also provide credit enhancement or, to a limited degree, grants. The designated state institution receives an initial flow of capital from EPA; local user fees are established to cover operation and maintenance costs and to repay loans and interest rates. As repayments accumulate, the SRF is able to make more loans using those repayments. The State of California, for example, uses its SRF for nonpoint source purposes. The fund is administered by the State Water Board, which developed a flexible program to evaluate and select for funding a wide variety of nonpoint source pollution projects. Eligible projects include construction of demonstration projects, retention/detention basins, and a variety of BMPs to reduce or remove pollutants. The nonpoint source program for the SRF also permits the establishment of substrate revolving funds that can provide funding to private individuals to finance new onsite septic systems.

Grants

Grants are sums of money awarded to state and local governments or nonprofit organizations that do not need to be repaid. Grants are awarded for the purpose of financing a particular activity or facility. EPA grants are federal grants that provide state and local governments funding to meet national environmental quality goals. Criteria for receiving grant money are established by EPA and must be met before the funds can be used for a specific activity or program. For example, section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) requires states to establish coastal nonpoint source control programs, which must be approved by both the National Oceanic and Atmospheric Administration (NOAA) and EPA. Once approved, the programs will be implemented through changes to the state nonpoint source pollution program approved and funded by EPA under section 319 of the Clean Water Act and through changes to the state coastal zone management program approved by NOAA under section 306 of the Coastal Zone Management Act. Section 604(b) of the Clean Water Act requires an allotment of funds to provide grants to states to carry out water quality management planning. Section 314 of the Clean Water Act provides funding for project grants to states for assessing the water quality of publicly owned lakes, developing lake restoration and protection plans, implementing these plans to restore and preserve the lake, and performing postrestoration monitoring to determine the longevity and effectiveness of restoration.

Leases

Leases are contracts that allow another person to use land or a building for a specific time, usually in return for repayment. Leasing obligations are not considered debt in most states and voter approval for financing is not required. Lease-purchase agreements (municipal lease) give the person holding the property lease, the lessee, the option of applying lease payments to the purchase of the facility. The lessee is responsible for paying taxes. These agreements can be used to finance wetland restoration projects or to purchase riparian areas or other environmentally sensitive areas. Sale-leaseback arrangements allow private investors to purchase public facilities or equipment on behalf of the community. Since the investors are entitled to tax benefits, they can lease the property back to the municipality at a lower cost.

Matching Wetland/Stormwater Factors to BMP Design

Preliminary Treatment of Stormwater

The level of treatment needed to protect a wetland that receives urban stormwater is dependent on the type and condition of the wetland; on the quality, quantity, and distribution of runoff; and on what levels of impacts to the wetland are considered acceptable. Ideally, all pollutants and sediments not present prior to watershed development should be removed before the stormwater is discharged to wetlands; however, some wetland types might be able to assimilate higher levels of certain pollutants. Some regions, such as southern Florida, parts of New England, and the Southwest, have soils with high infiltration rates, and a major concern related to urban stormwater might be the potential contamination of aquifers. Instituting stormwater treatment might be part of a larger effort to protect or restore wetland and downstream ecosystems and might involve analysis of stormwater dynamics at the watershed level and a variety of actions aimed at runoff quality maintenance or enhancement.

Matching Wetland Characteristics **to** BMP Design

Wetlands should be characterized with a classification system such as that of Cowardin and others (1979) prior to introducing additional stormwater or modifying the characteristics of existing stormwater inflows with BMPs. The general characteristics of a wetland, used to determine its placement in a classification system, should be considered when determining the type and placement of BMPs adjacent to or upstream of a wetland. In addition to considering general classification characteristics, site-specific evaluations of wetlands should be made. The modification of existing stormwater characteristics due to development or the type of BMPs used should be compatible with the characteristics of the existing wetlands in a system. Table 2-7 shows a general comparison of various BMPs and the benefits to protecting wetland functions that they might offer. This table is intended to be used as a preliminary screening device to identify potential wetland protection BMPs to treat stormwater runoff.

Hydrology

In addition to considering wetland type and conditions, the nature of stormwater discharges must be evaluated to determine the best practices for protecting urban wetlands. Both the quantity and quality of urban runoff are significantly affected by watershed development. Increased impervious area, removal of trees and other vegetation, and soil compaction in a watershed can increase runoff volume (Schueler, 1987), altering the natural hydroperiod of receiving wetlands. Reduced infiltration of stormwater can reduce baseflow and alter the groundwater hydrology of some urban wetlands. Known hydrologic impacts to wetlands associated with increased stormwater runoff include changes in wetland response time, changes in water levels in the wetland, and changes in the detention time of the wetland. Increased runoff volumes are also associated with greater water level fluctuations in receiving wetlands, which can adversely affect wetland plant and animal communities (Azous, 1991; Cooke, 1991). Large amounts of water entering a wetland at once can cause disturbance through changes in circulation and flushing characteristics and through possible erosion of wetland soils.

Table 2-7. Potential Benefits to Wetland Functions from Various BMPs

● =BENEFICIAL
◗ =BENEFICIAL WITH CERTAIN LIMITATIONS
=NEUTRAL

	Water Quality	Flood Control	Hydrology	Hydroperiod	Soils	Wetland Flora	Wetland Fauna	Primary Productivity	Nutrient Cycling/Availability	Erosion Control
Nonstructural BMPs										
Pollution Prevention	●				●	●	●	◗	◗	
Watershed Planning	●	●	●	●	●	●	●	●	●	●
Permitting Programs	●	●	●	●	●	●	●	●	●	●
Preventive Construction Techniques	●	●	●	●	●	●	●	●	●	●
Maintenance Activities	●	●	◗	◗	◗	●	●	◗	◗	●
Educational Programs	●	●	●	●	●	●	●	●	●	●
Riparian Areas	●	●	●	●	●	●	●	●	●	●
Structural BMPs										
Infiltration Basins	●	●	◗	◗	◗	◗	◗	◗	◗	●
Infiltration Trenches	●	●	◗	◗	◗	◗	◗	◗	◗	●
Sand Filters	●	◗	◗	◗	◗	◗	◗	◗	◗	●
Vegetated Filter Strips	●	◗	◗	◗	●	●	●	●	●	●
Vegetated Buffer Areas	●	●	●	●	●	●	●	●	●	●
Grassed Swales	◗	◗	◗	◗	◗	◗	◗	◗	◗	●
Open Spaces	●	●	●	●	●	●	●	●	●	●
Extended Detention Dry Basins	◗	●	◗	◗	◗	◗	◗	◗	◗	●
Wet Ponds	◗	●	◗	◗	◗	◗	◗	◗	◗	●
Constructed Wetlands	◗	●	◗	◗	◗	◗	◗	◗	◗	●
Porous Pavement and Concrete Grid Pavement	●	●	◗	◗	●	◗	◗	◗	◗	●
Oil/Grit Separators or Water Quality Inlets	●	●	◗	◗	◗	◗	◗	◗	◗	●
Level Spreaders Associated with Gabions	◗	●	●	◗	◗	●			●	●
French Drains	●	●	◗	◗	◗	◗	◗	◗	◗	●
Dry Wells or Roof Downspout Systems	●	●	◗	◗	◗	◗	◗	◗	◗	●
Exfiltration Trenches	●	●	◗	◗	◗	◗	◗	◗	◗	●
BMPs in Series	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗

The natural hydrologic characteristics of a wetland are of concern when designing stormwater management systems. In areas where natural wetlands are relatively unimpacted, the existing hydroperiod of wetlands should be maintained, while in areas where wetlands have been deprived of water, BMPs can play a role in enhancing wetland ecosystems through restoration of a more natural hydroperiod.

The source of water in a wetland is also important in designing a stormwater management system. In wetlands where the source of hydrology is primarily in the form of surface water runoff, the use of BMPs that incorporate infiltration into the soil as the method for stormwater treatment (e.g., infiltration trenches or infiltration ponds) might change the natural hydroperiod of adjacent or downstream wetlands. As mentioned, changes in the natural hydrologic characteristics can adversely affect the structure and functions of these wetlands. Stormwater treatment systems that treat stormwater by temporary detention or retention (e.g., extended detention ponds, wet ponds), when properly designed, can help to restore the predevelopment hydrologic conditions in this type of wetland. Conversely, the use of detention or retention systems adjacent to or upstream of groundwater wetlands can adversely affect their hydroperiod by altering natural baseflow conditions.

Climate

Local climatic conditions determine the quantity, frequency and intensity of stormwater runoff events. Under natural conditions, development of wetland types and functions is based largely on these climatic conditions. In fact, in the United States, climate variation has contributed to the formation of distinctly different wetland types, and climate is the second major controlling factor that leads to the formation of regional wetland types. Therefore, climatic conditions, precipitation, and storm events all need to be analyzed prior to selecting a stormwater pretreatment strategy The placement of BMPs to treat stormwater or to protect existing wetlands from stormwater impacts can actually harm the systems if the practices are not designed based on the local conditions and the natural wetland characteristics. Likewise, the selected BMP type and design should be based on both design storm requirements and adjacent wetland characteristics.

For example, stormwater in the Southwest is similar to that in other areas of the country. Some qualifications would include the following: (1) no major sodium chloride components in runoff from deicing salts as found in snow zones; (2) an increased dust component; (3) higher first-flush pollutant concentrations arising from a longer accumulation time between storm events; (4) suspended sediment sources masked by a high natural background; and (5) the desiccation of organic material on the landscape, especially domestic animal feces (Hawkins, 1993). Many urban areas in the Southwest lack storm sewers; streets and other land surfaces act as a conduit for stormwater, which enhances street runoff and contact with contaminants (Hawkins, 1993).

Any BMPs that require regular rainfall or a moist climate would not be appropriate for southwestern arid land conditions (Hawkins, 1993). Runoff is not frequent, stored stormwater is subject to high evaporation rates, and cover is naturally sparse. Traditional retention-type BMPs are used in the region, however, for peak flow reduction. Most of the water quality BMPs being proposed for southwestern cities stress dust and soil control, catch basin cleaning, debris removal, street sweeping, hazardous waste disposal, and other similar pollution prevention practices (Hawkins, 1993).

Water Quality

Natural nutrient levels within a particular wetland vary widely among wetland types, and the potential effects of loadings from stormwater must be evaluated with consideration of the type of receiving wetland. Wetlands can vary in their ability to absorb or transform these compounds due to variations in hydrologic, soil, and vegetative characteristics of the wetlands, and they might be only temporary sinks for some compounds. Although nitrogen can be removed from wetland soils as nitrogen gas through the process of denitrification, phosphorus can be held in wetland soils until a wetland's natural storage capacity is reached, beyond which the wetland might no longer function as a sink or might even become a net exporter of phosphorus to receiving waters (Richardson, 1989).

Pretreatment of stormwater flow prior to its inflow into existing wetlands can help in attenuating fluctuations in nutrient levels. The pretreatment of stormwater through the incorporation of BMPs can also reduce the amount of sediment that enters a wetland. If incoming sediment loads are high, the wetland's storage capacity could be reduced over time and its ability to function could be affected (Marble, 1992). While the increased levels of nutrient and sediment loading to wetlands associated with stormwater can adversely affect wetland functional characteristics, the removal of most or all suspended particulates through the placement of BMPs can also result in wetland degradation. Reductions in the natural levels of sediment deposition in a wetland can result in the embedding of downstream wetland substrates in some wetland types or in erosion in other types and potentially in erosion and channel scouring in associated downstream systems. In some systems the resuspension of downstream floodplain sediments can occur. Natural soil and sediment conditions should be considered in a wetland or wetland system when determining the feasibility, design, and types of BMPs to be used.

Monitoring

One strategy for determining the performance of a BMP - its effect on the wetland's water quality, health, and functions -is through monitoring. Even though monitoring is beyond the scope of this manual, it is worthwhile to discuss the fundamentals of a monitoring project. During the BMP planning process, the appropriate level of monitoring should be determined so that resource requirements can be identified and factored into the overall project. Proper planning targets monitoring efforts at key elements of the project that will indicate the degree of success and the potential need or opportunity for improvement in a particular system.

A monitoring plan should be developed based on the objectives of the BMP project and on documented literature or readily available monitoring results of similar projects (Kusler and Kentula, 1990; USEPA, 1992). The wetland functions of concern should be identified and the current level of those functions established relative to reference wetlands. For an existing wetland, functions that might be threatened by stormwater runoff (e.g., sediment retention and long-term water storage) should be documented. Where stormwater might be used to restore a severely degraded wetland, the desired functions of the wetland should be evaluated so progress can be measured.

The first step in any monitoring effort, establishing baseline data, is important in evaluating the long-term effectiveness of the BMP. Obtaining as much information as possible about the resource to be protected or restored will allow progress or degradation to be measured. As soon as construction of the BMP is completed, monitoring of the project should begin. For a thorough monitoring effort, the boundaries of the watershed in which the BMP was constructed should be determined and the exact location of the project within that watershed should be indicated on a map. Variables that might be included in a monitoring effort include the following (North Carolina Cooperative Extension Service, 1995; USEPA, 1992a):

- Morphometry (area, slope, and perimeter-to-area ratio)
- Hydrology (water depth, flow rates, flow patterns, and indirect indicators)
- Substrate (soil depth, color, texture, source, organic matter, sediment flux)
- Vegetation (species, coverage, survivorship)
- Fauna (observations, habitat evaluation, species- or community-specific sampling)
- Water quality (pH, DO, temperature, metals, turbidity, TSS, BOD, N, P)

Monitoring strategies might range from simple visual assessments of a wetland to full evaluations including ambient water quality analyses in the wetland and a BMP inlet/outlet efficiency assessment. In some cases, the simple, visual assessments (e.g., looking at the vegetation and hydrologic changes) might be enough monitoring to determine whether the BMP is performing efficiently When this simple monitoring does not provide adequate information, more elaborate analysis is needed.

It is advisable to identify and take into account other existing information that might be available, such as meteorological data, data obtained from monitoring conducted under an NPDES or state permit, or volunteer monitoring data. A sampling regime including set (or randomly selected) sampling sites and specific times to repeat the sampling (e.g., in wet and dry seasons) should be established. A site can be monitored through routine inspections or more comprehensive, quantitative sampling events. Routine inspections are “spot checks" and are conducted as often as daily or weekly. These assessments allow the investigator to identify problems as they develop. Generally routine inspections are less costly and not as damaging to the wetland or BMP because these inspections are less intrusive (i.e., they require less data collection and less equipment to obtain the data).

Quantitative sampling events, in comparison, are periodic assessments conducted annually for several years after the BMP is constructed. This type of monitoring indicates the degree to which the goals of the project have been met (Kusler and Kentula, 1990). Comprehensive assessments typically require more equipment and skilled personnel and therefore are more costly and often more damaging to the wetland than are routine inspections.

Reports of monitoring efforts should include photographs of each sampling effort, a description of the project and project site, an explanation of site preparation, and a summary of what was conducted and the results. These data, once evaluated, will allow for improvements in design guidelines for future BMP projects.

The data quality of monitoring efforts must be scientifically acceptable. Five quality assurance components of assessments have been identified: precision of the measurements of the same variable, accuracy of the measurements, completeness of the collected data versus what was expected, representativeness of the variable’s characteristics, and comparability of one data set to another (Sherman et al., 1991, cited in USEPA, 1992a).

Summary

Best management practices used for the treatment of urban stormwater are commonly located in low topographic positions adjacent to or within existing wetlands. They can be used primarily to treat or pretreat stormwater or to protect existing wetlands from the effects of stormwater runoff. The above examples represent only a few of the variables that should be considered when placing BMPs within or adjacent to wetland systems. When designing BMPs, the treatment of stormwater is not the sole consideration. For BMPs that are incorporated into systems where wetland protection and optimal stormwater treatment are both objectives, the characteristics. of the existing wetlands must also be considered. It is most desirable to consider protecting wetland resources from a holistic perspective. This can be accomplished through the use of a variety of nonstructural BMPs including watershed planning, public education, and preventive construction techniques.

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Section 3
Case Studies

Introduction

To illustrate how BMPs have been incorporated with wetlands into urban stormwater management systems, several case studies are presented. The purpose of the case studies is to illustrate measures that can be taken to prevent adverse impacts to wetlands from stormwater runoff. In most of the case studies, wetlands were incorporated into the stormwater management system for the site. Generally, some type of treatment was provided to reduce pollutants in the stormwater before its discharge to natural wetlands. Available water quality data are presented, as well as information regarding habitat change. The case studies are presented by EPA Region, and by wetland type and BMP applicability. The following list correlates BMPs used in the case studies to applicable BMP fact sheets in Section 4.

Case Study-BMP Fact Sheet Correlation

EPA Region 1

Narrow River Special Area Management Plan

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Preventive Construction Techniques (See BMP Fact Sheet p. 4-12)
Grassed Swales (See BMP Fact Sheetp. 4-32)
Extended Detention Dry-Basins (See BMP Fact Sheet p. 4-43)

EPA Region 2

Freshwater Wetlands Protection Act

Extended Detention Dry Basins (See BMP Fact Sheet p. 4-43)
Contour Terraces
Grassed Swales (See BMP Fact Sheet p. 4-32)
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Outreach and Educational Programs (See BMP Fact Sheet p. 4-13)
Pollution Prevention (See BMP Fact Sheet p. 4-2)

EPA Region 3

Watershed Management Study

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)
Wet Ponds (See BMP Fact Sheet p. 4-47)
Road Culvert Retrofit
Riparian Areas (See BMP Fact Sheet p. 4-18)

EPA Region 4

Hidden River Wetland Stormwater Treatment Site

Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)
Construction Sedimentation Basins
Grassed Swales (See BMP Fact Sheet p. 4-32)

EPA Region 5

Lake McCarrons Wetland Treatment System

Construction Sedimentation Pond
Level Spreaders (See BMP Fact Sheet p. 4-61)
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)

The Phalen Chain of Lakes Watershed Partnership

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Outreach and Educational Programs (See BMP Fact Sheet p. 4-13)
Grassed Swales (See BMP Fact Sheet p. 4-32)
Open Spaces (See BMP Fact Sheet p. 4-41)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)
Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)

The Prairie Wolf Slough Project

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Outreach and Educational Programs (See BMP Fact Sheet p. 4-13)
Constructed Wetlands (See BMP Fact Sheet p. 450)
Open Spaces (See BMP Fact Sheet p. 4-41)

EPA Region 6

Tensas Cooperative River Basin Study

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Vegetated Filter Strips (See BMP Fact Sheet p. 4-35)
Grassed Swales (See BMP Fact Sheet p. 4-32)

Water and Sediment Control Basins
Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)
Pollution Prevention (See BMP Fact Sheet p. 4-2)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)

EPA Region 7

Multi-Species Riparian Buffer Strips, Bear Creek Watershed

Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)
Vegetated Filter Strips (See BMP Fact Sheet p. 4-35)
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Pollution Prevention (See BMP Fact Sheet p. 4-2)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)

EPA Region 8

A Watershed Approach to Municipal Stormwater Management

Outreach and Educational Programs (See BMP Fact Sheet p. 4-13)
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Grassed Swales (See BMP Fact Sheet p. 4-32)
Infiltration Basins (See BMP Fact Sheet p. 4-20)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)
Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)
Vegetated Filter Strips (See BMP Fact Sheet p. 4-35)
Pollution Prevention (See BMP Fact Sheet p. 4-2)

Lemna Nonpoint Source Treatment System

Wet Ponds (See BMP Fact Sheet p. 4-47)
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Constructed Wetlands (See BMP Fact Sheet p. 4-50)

EPA Region 9

Lincoln-Alvarado Project

Oil/Grit Separators (See BMP Fact Sheet p. 4-58)
Vegetated Filter Strips (See BMP Fact Sheet p. 4-35)

EPA Region 10

Sawmill Creek

Riparian Areas (See BMP Fact Sheet p. 4-18)
Vegetated Natural Buffers (See BMP Fact Sheet p. 4-38)

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Fencing of Riparian Pasture
Upland Water Troughs for Livestock
Planting of Willow Cuttings

Sublett Creek Restoration Project

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Grazing Allotment Management Plan (AMP)
Planting of Willow Cuttings
Drift Fences
Log Dams
Upland Water Troughs for Livestock

Bear Creek *Restoration Project*

Sedimentation Basins
Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Fencing Riparian Pasture
Riprap
Upland Spring Sites for Livestock

Camp Creek *Restoration*

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Sedimentation Basins
Fencing Riparian Pasture
Planting of Willow Cuttings
Riprap
Low-rock Structures and Gabions
Outreach and Educational Programs (See BMP Fact Sheet p. 4-13)

The Chewaucan River

Watershed Management Plans (See BMP Fact Sheet p. 4-8)
Riparian Areas (See BMP Fact Sheet p. 4-18)
Riprap
Snag Removal
Fencing Riparian Pasture
Planting of Willow Cuttings
Exclusion of Cattle Grazing

Regional Case Studies

EPA Region 1

Narrow River Special Area Management Plan, Rhode Island

The Narrow (Pettaquamscutt) River watershed is located in southern Rhode Island in the towns of North Kingstown, South Kingstown, and Narragansett. The watershed drains into southwestern Narragansett Bay and encompasses several unique water bodies (Figure 3-l).

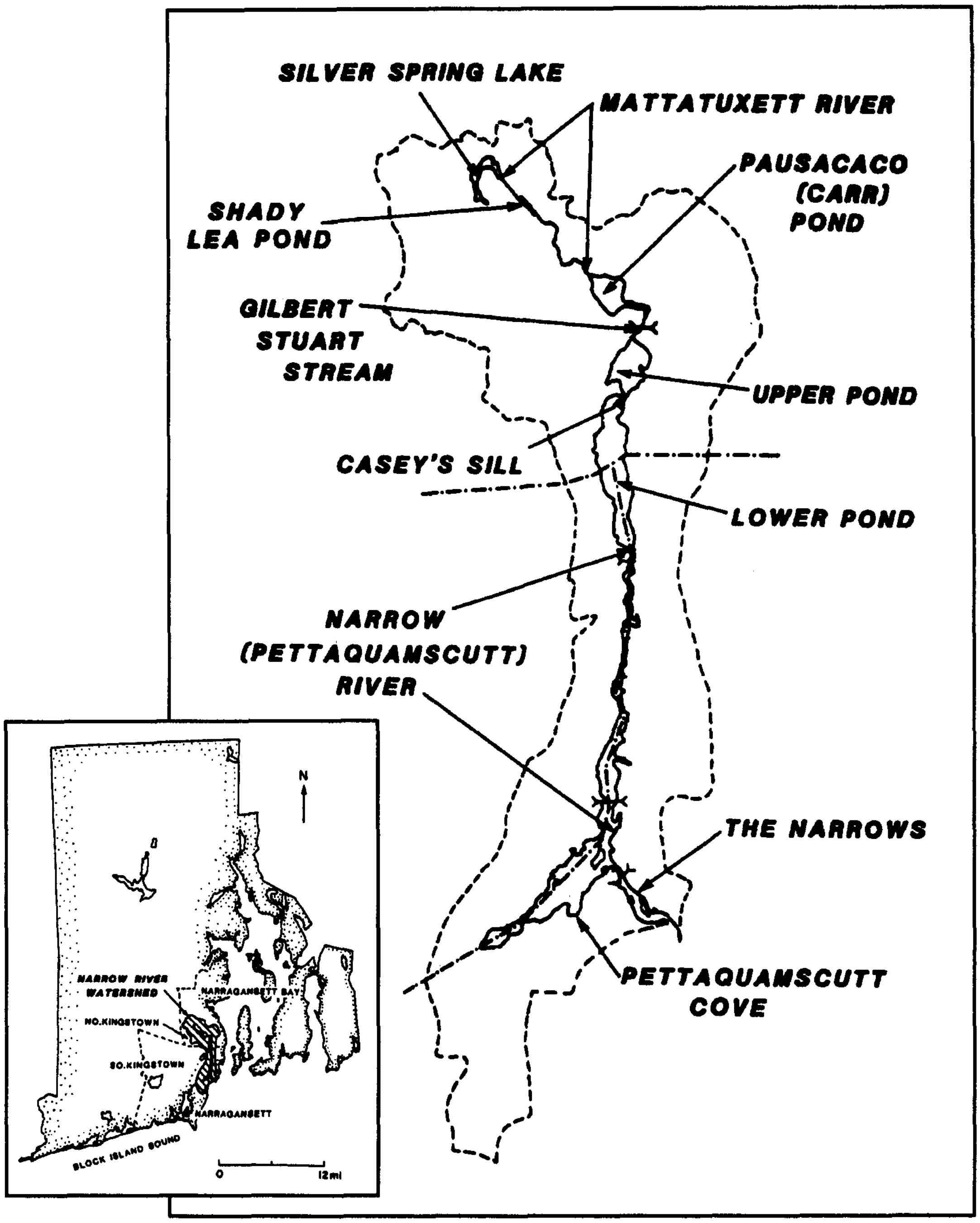

Figure 3-1. Location** of the **Narrow River watershed study area in the State of Rhode Island.

Known use of the river and its resources extends back to at least 3,000 years ago when Native Americans hunted and gathered along the river. Other uses of the river have included ship building, agriculture, dairy farming, summer housing, and permanent homes. The Narrow River watershed is rich in recreational resources such as boating, camping, hiking, fishing, swimming, and birdwatching, and the river valley is considered one of Rhode Island's most scenic areas.

Wildlife inhabit Narrow River and its watershed for breeding, nesting, spawning grounds, and migratory bird routes. Several threatened and endangered species, including species of marsh grass, osprey, Least Tern, sea cucumber, moonfish, luminescent moss, and several fern species are known to inhabit the area.

Coastal wetlands in Rhode Island have been altered and destroyed by development activities, which impact wetlands by filling, removing vegetation, grading, dredging, excavating, draining, damming, and diverting the hydrologic flows into the wetlands. Alteration of the adjacent land areas has affected local drainage patterns, thereby altering the sedimentation processes and salinities of waters that enter wetlands. Building practices, human encroachment, and other development pressures have caused water quality degradation, impacted critical habitat areas, reduced public access, and spoiled aesthetic values throughout the watershed.

In response to coastal wetlands loss, the Rhode Island Coastal Resources Management Council (CRMC) has set goals to protect, preserve, and where possible restore coastal wetlands. CRMC supports a policy of "no net loss" of coastal wetland acreage and functions and requires a 2:1 mitigation ratio of replacement or creation of coastal wetland to areas permanently altered or lost. (Wetlands created for stormwater management, erosion control, or waste management are exempt from mitigation requirements.)

Past management efforts to protect the Narrow River and its watershed were undertaken by the Narrow River Preservation Association (NRPA), the Narrow River Watershed Advisory Council, and the Narrow River Land Trust. NRPA, founded in 1970, initiated the first planning study of the watershed, which resulted in a report describing the development trends and impacts to the river, and made recommendations for development control. The Narrow River Watershed Advisory Council, formed in 1981, was a group of representatives from North Kingstown, South Kingstown, and Narragansett, whose objective was to promote the protection of the watershed's values. The Council appointed the Narrow River Watershed Advisory Committee, which developed a watershed program, recommended policies, and collected and analyzed resource data. The Narrow River Land Trust, created in 1983, is a nonprofit organization that obtains property and property rights for protection of natural resources.

Special Area Management plans (SAMPs) have been developed at the local and national levels as management strategies for environmental planning. SAMPs focus the legislative and regulatory powers of the CRMC to the specific problems of the designated resource. The effort to create a SAMP for the Narrow River watershed began in September 1985 as an adaptation of the SAMP that existed for the salt pond region of southern Rhode Island. It resulted from the general belief that activities in the Narrow River's watershed needed stronger management.

One of the first steps in designing the plan was to create a comprehensive characterization of the watershed. Available research conducted by consulting firms, students, scientists from the University of Rhode Island, and state agencies and town records were reviewed to determine past and present problems in the watershed and to develop management strategies and initiatives to address those problems.

At the beginning of the planning process, September 24,1985, CRMC imposed a building moratorium on all development applications within an area 200 ft (60.96 m) inland of mean high water, or the inland edge of a wetland, bluff, river bank, or other coastal feature. The moratorium also applied to all CRMC permits required by facilities requiring a parking area (at least 1 acre in size) and by subdivisions of six units or more. Applications submitted after the end of the moratorium, December 31,1986, were subject to the guidelines and regulations set forth in the SAM plan.

The focus of the SAM plan was to address several problems that had not been adequately addressed in past management efforts: degradation in water quality, development pressures and human encroachment into areas unsuitable for building, potential loss of wildlife species and habitat, and loss of aesthetic values. The SAM plan for the Narrow River watershed regulates the following:

- Land classification for watershed protection
- Watershed controls for stormwater management
- Watershed controls for septic system management
- Watershed controls for erosion and sedimentation
- Lands requiring special considerations (historic/archaeological value)
- Petroleum tanks and oil spills
- Community participation
- Future research efforts

Stormwater management is highlighted here because the SAM plan regulates stormwater as a means to protect wetlands. The plan defines stormwater management as the quantitative control of increased volume or rate of runoff and the qualitative control of runoff through a system of vegetative and structural measures to prevent pollutants from being transported in runoff.

Stormwater management is required for all new residential developments six units or more, all facilities and activities requiring 20,000 ft^2 (1,800 m^2) or more of impermeable surface area or resulting in 20 percent or more of the project area being impervious, and all roadway construction and upgrade projects. Stormwater management is also required for activities that will involve alteration, maintenance, or improvement to an existing stormwater management structure that will alter the quality, rate, volume, or location of surface water discharge.

CRMC requires the stormwater management plan to include information on existing conditions as well as predicted conditions after the activity is implemented. A stormwater management plan must include maps, charts, graphs, tables, photographs, descriptions, and other supporting documentation.

The stormwater management plan must provide evidence that structures were planned and designed and will be constructed to ensure that postdevelopment runoff, hydrodynamic characteristics of the watershed and groundwater, and wetland functions and values are the same as predevelopment conditions. Postdevelopment conditions must also prevent increased flooding, damage, and saltwater intrusion; must protect natural fluctuating levels of salinity in estuarine areas; and must minimize alterations to flora, fauna, and habitat that could result from improper construction, design, and location of the structures.

Design, construction, and maintenance of stormwater systems may not allow the direct discharge of runoff into Narrow River and its tributaries. CRMC also prohibits increasing the volume or rate of runoff or further degrading the quality of existing discharges. Discharges must be routed through vegetated swales or other structural or nonstructural systems that increase time of concentration, decrease velocity, increase infiltration, allow suspended solids to settle, and remove pollutants. These systems should use overland flow and reinfiltration as priority techniques for the treatment of runoff. Detention and retention ponds may not be located in areas that might cause groundwater contamination.

Stormwater management is only one component of the SAM plan, and CRMC recognizes that future management improvements and further research efforts are needed to protect the natural resources of the Narrow River watershed. CRMC has recommended the following areas for further research:

- Monitoring of the river's water quality
- Development of a hydrodynamic model of the estuary
- Analysis of bottom sediment (distribution, composition, and transport dynamics)
- Studies of water quality in the northern regions of the watershed
- Determination of the current status of the quality and quantity of groundwater resources
- Initiation of water quality testing in the freshwater systems in the northern regions of the watershed
- The state and towns collectively undertaking stormwater management techniques to upgrade or create programs

Reference/Additional Information

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EPA Region 2

Freshwater Wetlands Protection Act, State of New Jersey

The protection of wetlands has long been a priority in the State of New Jersey, (NJDEP 1995). To protect these vital areas, the New Jersey legislature passed the Wet lands Act in 1970 and the Freshwater Wetlands Protection Act in 1987. These acts and their corresponding regulations require approval by the New Jersey Department of Environmental Protection (NJDEP) for a number of proposed activities that could impact wetlands (both freshwater and saltwater). This discussion focuses on New Jersey's Freshwater Wetlands Protection Act and its subsequent rules regarding stormwater facilities.

Wetlands receive the same protection granted surface waters under the state's water quality standards (N.J.A.C. 13:9B-13 and N.J.A.C. 7:7A-35(a)4). In addition to restrictions protecting the wetlands themselves, restrictions placed on areas surrounding the wetlands offer further protection for freshwater wetlands. These areas are designated "transition areas" in the state's Freshwater Wetlands Protection Act Rules (N.J.A.C. 7:7A-6.1). The Freshwater Wetlands Protection Act requires a transition area adjacent to wetlands of "exceptional" or "intermediate" resource value. Freshwater wetlands of "ordinary" resource value, which constitute approximately 5 percent of New Jersey's wetland area, do not require a transition area.

The standard width of the transition area adjacent to a freshwater wetland of intermediate resource value is 50 ft (15.24 m) and for freshwater wetlands of exceptional value is 150 ft (45.72 m). Wetlands of exceptional resource value require an individual permit, and mitigation must be provided. Further, applicants for activities proposed in wetlands of exceptional resource value must demonstrate either that there is a compelling public need for the proposed activity which is greater than the need to protect the wetland or that denial of the permit would impose extraordinary hardship.

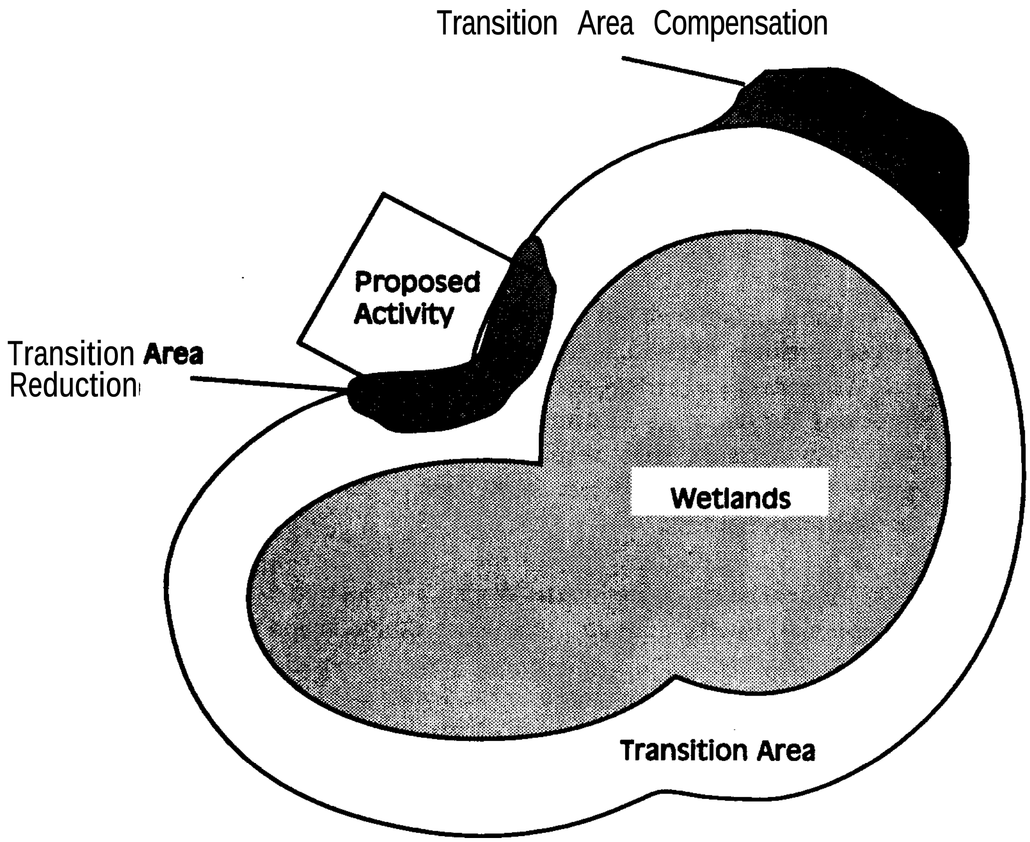
As defined in the Freshwater Wetlands Protection Act Rules, freshwater wetlands of exceptional resource value are those which exhibit any of the following characteristics:

- Those which discharge into FW-1 waters or FW-2 trout production waters or their tributaries (FW-1 and FW-2 are water-quality rankings for fresh surface waters in New Jersey) or
- Those which are present habitats for threatened or endangered species, or those which are documented habitats for threatened or endangered species, and which remain suitable for breeding, resting, or feeding by these species during the normal period when these species would use the habitat.

Freshwater wetlands of ordinary resource value are those which (1) do not exhibit the characteristics above, (2) are isolated wetlands that are more than 50 percent surrounded by development, and (3) are less than 5,000 ft^2 (450 m^2) in size including but not limited to drainage ditches, swales, and detention facilities. Freshwater wetlands of intermediate resource value are those which are not defined as either exceptional or ordinary

The Freshwater Wetlands Protection Act Rules also have requirements related to pretreatment practices for the protection of wetlands (N.J.A.C. 7:7A-9.2(a) 11, v, ix, and x.) Under the state's general permit requirements, pretreatment of stormwater is required for stormwater flows entering natural wetlands regardless of resource value. All stormwater discharged into a freshwater wetland from a stormwater outfall must first be filtered or otherwise treated outside the freshwater wetland (NJDEPE, 1992). Detention basins, contour terraces, and grassed swales are examples of predischarge techniques that may be required by the NJDEP The general permit does not authorize placement of detention facilities in freshwater wetlands and requires compensation for disturbance within the wetland transition area (see Figure 3-2). Other stormwater facility design restrictions include the following:

- The total amount of riprap or any other material used for energy dissipation at the end of the headwall placed in the freshwater wetland cannot exceed 10 cubic yards per outfall structure.
- Excavated areas for the placement of conveyance pipes must be returned to the preexisting elevation using the original topsoil to backfill from a depth of 18 in (45.72 cm) to the original grade and must be revegetated with indigenous wetland species.



NJDEP, 1995.

Figure 3-2. Example of a transition area reduction and compensation.

- Pipes used for stormwater conveyance through the wetlands must be designed not to exceed the preexisting elevation and properly sealed with anti-seep collars at a spacing sufficient to prevent drainage of the surrounding wetlands.
- If a detention basin is being proposed as the method of pretreatment for water quality routing calculations must show that the basin has been designed for the l-year storm event according to the New Jersey Stormwater Management Regulations (N.J.A.C. 7:8).
- If a swale is being proposed to convey stormwater through the wetlands, profiles from the outlet to the receiving water body, cross-sections, and design support information must show that the proposed swale will not result in drainage of the wetlands. Swales in wetlands are permitted only where onsite conditions prohibit the construction of a buried pipe to convey stormwater to an outfall.

The NJDEP works with property owners on a case-by-case basis to determine the most appropriate stormwater treatment method to protect wetlands from both physical disturbance and potential impacts from stormwater discharges. Where new development is proposed adjacent to freshwater wetlands and preliminary treatment of stormwater is required to meet state water quality standards, NJDEP staff make the final decisions on the location and design of each BMP.

References/Additional Information:

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EPA Region 3

Watershed Management Study, Prince William County, Virginia

Three watersheds in Prince William County, Virginia, are the subject of a 5-year interdisciplinary, intergovernmental (federal-state-local) watershed management study (see Figure 3-3). The study includes the protection of wetlands through the use of a variety of BMPs and the restoration of degraded riparian wetlands following the installation of upstream controls. The purpose of the project is to develop an innovative stormwater management plan and several demonstration projects that take a watershed approach to environmentally sensitive decision making. The headwaters of the three watersheds being studied are located in the Piedmont physiographic province, cross the fall line, and drain into the tidal portion of the Potomac River Estuary within the Mid-Atlantic Coastal Plain. The area of study within the watersheds consists entirely of the portions to the west of Interstate 95 in the Piedmont province.

The northernmost watershed, Neabsco Creek (13,047 acres or 5,284 hectares), experienced substantial urban/suburban development before stormwater and nonpoint source controls became a requirement. The large planned community of Dale City is located in the Neabsco Creek watershed, as is the Potomac Mills shopping complex. The center watershed, Powells Creek (11,762 acres or 4,764 hectares), is predominantly rural, forested land that is experiencing development pressure. The southernmost watershed, Quantico Creek (24,636 acres or 9,978 hectares), the majority of which is currently owned by the National Park Service and the U.S. Marine Corps, is largely undeveloped and is likely to remain so.

All of the watersheds were extensively logged beginning in colonial times, and logging continued periodically through the 19th century In addition, the Quantico Creek watershed was the site of both agricultural activities and active pyrite mining for sulfur into the 20th century Nonetheless, the habitat quality of the streams and wetlands is high throughout the upper watershed and therefore the Quantico Creek watershed has the potential to be used as a control site during the study The intention is for the Quantico Creek watershed riparian and wetland habitats to serve as benchmarks for habitat quality goals established for the Neabsco Creek and Powells Creek watersheds. Stream rapid bioassessments have been conducted in all three of the watersheds, allowing comparisons of current habitat conditions. Water quality and quantity monitoring is also being conducted along all three streams.

Riparian floodplain forests located along the Piedmont streams are the dominant nontidal wetland type that has been identified in the study area to date. National Wetlands Inventory maps indicate temporarily flooded (PFOlA) and seasonally flooded (PFOlC) palustrine forested wetland communities. Because much of the land was in agriculture relatively recently (farming generally ceased between 25 and 60 years ago), the forests range from successional to mature communities dominated by red maple *(Acer rubrum),* sycamore *(Platanus occidentalis),* and pin oak

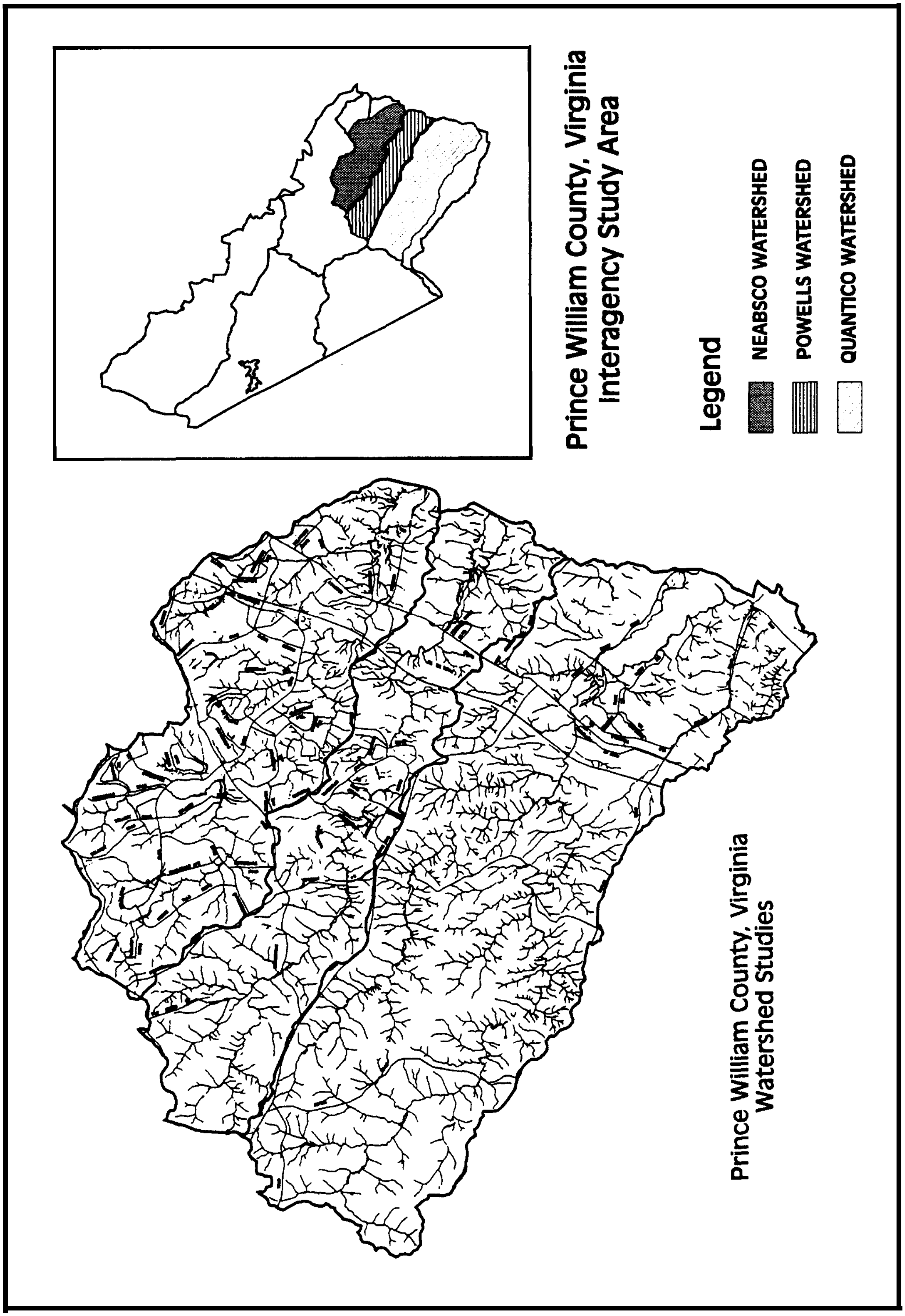


Figure 3-3. Prince William County, Virginia, watershed studies.

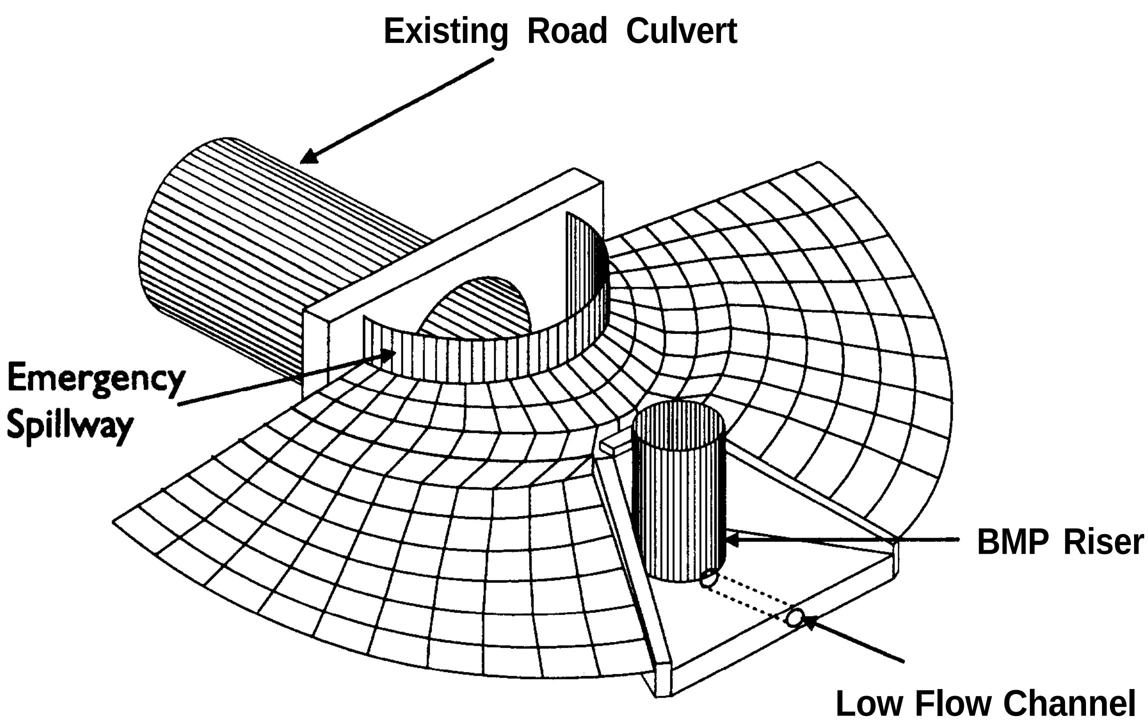
(Quercus palustris). Common understory species include musclewood *(Carpinus caroliniana),* spicebush *(Lindera benzoin),* Japanese honeysuckle *(Lonicera japonica),* and greenbriar *(Similax rotundifolia).* Emergent wetland communities that have become established in impounded areas, such as old farm ponds and some stormwater basins, include cattail *(Typha latifolia),* smooth alder *(Alnus serrulata),* soft rush *(Juncus effusus),* and wool grass *(Scirpus cyperinus).*

A federal interagency team consisting of the U.S Army Corps of Engineers (Corps), the U.S. Fish and Wildlife Service (USFWS), and the U.S. Environmental Protection Agency (EPA) conducted preliminary wetland assessments in 1992 for portions of the Powells Creek and Neabsco Creek watersheds. The team focused its assessment on forested wetlands and relied on a combination of the Army Corps of Engineers' Wetland Evaluation Technique (WET II) and best professional judgment. Results of the assessment indicated that floodplain forests in both watersheds have high effectiveness and good potential for floodplain storage, sediment retention, and nutrient removal functions. Opportunity for these functions to be performed is greater in the intensely developed Neabsco Creek watershed. Because of the extensive development, the wetlands in the Neabsco Creek watershed are smaller and more fragmented than those in the adjacent, relatively undeveloped Powells Creek watershed. The riparian areas and floodplain wetlands along Powells Creek are larger and more contiguous, providing greater overall wildlife habitat functions.

The assessment also indicated that deep stream entrenchment caused by increased frequency, duration, and intensity of stormwater flows in the Neabsco Creek watershed appeared to be affecting the hydrology of adjacent wetlands. Ironically, despite this degradation, the Neabsco Creek wetlands were determined to have high educational and recreational value because of their proximity to population centers. The U.S. Fish and Wildlife Service, in cooperation with the Prince William County Public Works Department, is working on several stream/wetland restoration projects along Neabsco Creek.

The structural stormwater management facilities being evaluated as part of the study include onsite and regional BMPs. Nonstructural BMPs include riparian buffers and stream restoration techniques. Several of these practices are currently protecting downstream wetlands from the impacts of urban stormwater discharges.

- A regional wet pond is located immediately upstream from a substantial riparian wetland area along Neabsco Creek adjacent to a shopping center. The BMP pond, which controls a drainage area of approximately 300 acres (122 hectares), is intended to protect the downstream wetlands from erosive velocities and to improve water quality A restoration plan has been prepared for approximately 1 mi (1.6 km) of stream channel, 6 acres (2.4 hectares) of associated riparian forest, and 20 acres (8.1 hectares) of emergent wetland habitat, which are located immediately downstream of the regional BMP pond.
- A "road culvert retrofit BMP" that essentially functions as an extended detention BMP facility has been established on an unnamed tributary on Neabsco Creek. The upstream drainage area is more than 200 acres (81 hectares) and is intensely developed with residential and commercial land uses. The immediate area includes a shopping center located adjacent to the stream upstream of the culvert. A riser was initially constructed upstream of a wing wall (concrete apron) built in front of the existing road culvert (see Figure 3-4). The design is being modified to incorporate a small permanent pool behind the wing wall and the use of a hydraulic jump to provide the outlet for the 2-year storm rather than the use of the riser. The design modifications were necessary because during



Prince William County, 1994.

Figure 3-4. Isometric view of the Neabsco Creek tributary road culvert retrofit BMP.

the winter of 1994 the riser became clogged with debris and local officials perceived the ponded area to be too large.

The road culvert retrofit BMP works by ponding the more frequent storms, which cause sediment-laden water to overflow the stream banks in the backwater area and deposit its solids load in the riparian floodplain. This BMP protects downstream riparian wetlands from the erosive peak velocities and durations associated with frequently occurring storm events. The specific water quality benefits of the BMP are being studied as part of the comprehensive 5year watershed program. Automatic sampling and flow-gauging equipment has been installed and is providing data on hydrology and pollutant transport. The water quality monitoring information that will be collected and analyzed by the Virginia Polytechnic Institute and State University (Virginia Tech) includes:

- Flow
- Nutrients: total phosphorus, soluble reactive phosphorus, soluble aluminum, total Kjeldahl nitrogen, and oxidized nitrogen
- Dissolved oxygen, pH, conductivity, alkalinity and hardness
- Trace metals
- Biochemical oxygen demand and chemical oxygen demand
- Total suspended solids
- Total organic carbon

Prince William County intends to install additional road culvert retrofit BMPs in other areas of the county during the program. Watersheds of about 80 acres (32 hectares) are being targeted for these BMPs. The BMPs will allow the floodplain forests that are inundated to realize the high potential effectiveness for sediment retention and nutrient removal functions identified by the WET II/BPJ analysis described above. Another potential benefit of this innovative BMP is to minimize the impact on wetlands. If provided in series throughout a watershed, these BMPs have the potential to provide substantial water quality improvements and possible wetland protection with a minimum of disruption to the natural ecosystem (i.e., displacement of natural wetlands by large stormwater management ponds).

Riparian wetland areas have been identified and delineated in the Powells Creek watershed. BMPs designed for the improvement of water quality and the protection of riparian wetlands have been planned and installed to protect some of these wetland areas. These include numerous onsite BMP ponds in residential and commercial developments throughout the watershed, a regional pond currently in design, stream restoration plans, and two farm pond retrofit projects.

The multiple stakeholders, the interdisciplinary approach, and the long-term aspects of the program are unique. The comprehensive approach being taken in the project contains elements that cut across traditional federal and local roles. For example, program elements include flood protection, stormwater management, erosion and sediment control, wetland preservation, water quality and terrestrial as well as aquatic habitat quality. Prince William County is funding more than 50 percent of the project. The U.S. Geological Survey (USGS) is involved in the stream gauging and water quality monitoring components of the project. In addition to the USGS, the Corps, the USFWS, and EPA are providing federal agency involvement and funding to varying degrees. The Virginia Department of Environmental Quality and the Chesapeake Bay Local Assistance Department (a state agency that implements Virginia's Chesapeake Bay Preservation Act) are providing funding and/or monitoring and other technical support. Two state universities, George Mason and Virginia Tech, are providing technical support in the form of bioassessments and water quality monitoring, respectively

Initial data collection for the project will continue through 1997. An environmental history of the watersheds will be compiled using baseline water quality monitoring data, land use information, and an evaluation of data collected on terrestrial and aquatic resources. Traditional and innovative BMPs for stormwater and nonpoint source controls will be tested and evaluated. The design of stormwater management facilities will attempt to replicate the hydrologic characteristics of the watershed based on modeled predevelopment conditions. (These results could ultimately be compared to field data collected in the Quantico Creek watershed, for the "predeveloped case.") Ultimately, the project is attempting to document the cumulative impacts that result as urbanization degrades water resources and ways in which sound watershed management might mitigate water quality problems and related habitat problems. The results of this comprehensive approach to preserving the environmental integrity of a developing watershed should be useful to all stakeholders. Prince William County will benefit by being able to use the data to determine the best approach for managing its other watersheds.

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EPA Region 4

Hidden River Wetland Stormwater Treatment Site, Tampa Florida

Hidden River Wetland is a natural wetland located in the Hidden River Corporate Park in Tampa, Florida. The 3-acre (1.2 hectares) wetland receives runoff from a mostly impervious drainage basin approximately 15 acres (6 hectares) in size that includes an office park complex, parking lots, and a central roadway The wetland-to-upland ratio of the stormwater treatment site is approximately 15 or 20 percent (i.e., about 80 percent of the treatment site is upland). Annual precipitation in the region is about 52 in (132.08 cm) per year. Water leaving the wetland flows into the Hillsborough River via an alluvial floodplain. Water quality of the Hillsborough River is good near Hidden River; however, it becomes degraded downstream at Tampa because of factors not related to this site.

Hidden River Wetland is a freshwater, herbaceous marsh, classified as a palustrine emergent wetland. In southwest Florida there are many isolated wetlands of this type, known locally as Florida flag marshes. These wetlands have highly reduced organic soils. Hidden River Wetland has 95 percent vegetation cover; the plant community is dominated by maidencane *(Panicum hemitomom),* pickerelweed *(Pontederia cordara),* and waterlily *(Nymphaea odorara).* The wetland was undisturbed prior to site development. Construction of a roadway filling a portion of the south end of the marsh necessitated the construction of a small mitigation area to the east side of the marsh. The north rim of the marsh is protected by a buffer of native vegetation.

Runoff enters the system through two inlets and undergoes preliminary treatment in two sedimentation basins that were built in 1987 as part of the stormwater management system to protect the wetland. The east sediment basin consists of approximately 0.2 acre (784.08 m^2) of open water, while the west basin, which is usually dry, covers about 0.07 acre (274.43 m^2) and is vegetated with cattails *(Typha latifolia)* and other plant species. The west basin has a very wide, brief water level fluctuation. Rain events of over 0.5 in (1.27 cm) generally produce flows into the wetland for less than a day; however, discharges from the wetland do not occur until July and then are continuous until September. Wetland outflow is treated in a grassed swale before it enters a lower detention pond. After passing through a forested alluvial floodplain, the outflow enters the Hillsborough River.

After several years of use, Hidden River Wetland continues to have a beneficial effect on water quality. Generally, inorganic nitrogen, phosphorus, and suspended solid concentrations are lower in the wetland outflow than in the inflows. Water in the wetland maintains lower pH, dissolved oxygen, and reduction/oxidation potential than the inflowing waters. Fluctuations in water quality are much greater in the sedimentation basins than in the wetland. Water temperatures in the wetland are as much as 10 degrees Celsius lower than those in the sedimentation basin.

Although a plant survey was not conducted prior to sedimentation pond construction and site development, a comparison of aerial imagery from 1984 and 1992 suggests that the discharge of pretreated stormwater to the wetland has caused a reduction in open water area of the wetland but has had little effect on which plant species are present. The typical seasonal variation of water level in Florida flag marshes, including a dry winter period, has been maintained. The pH of the wetland is slightly acidic rather than the circumneutral pH typical of Florida flag marshes, which might be due to acidic groundwater influences. Conductivities are also lower than usual for flag marshes. Where the edge of the wetland vegetative community was disturbed by landscaping activities, cattails *(Typha latifolia)* and primrose willow *(Ludwigia peruviana)* have invaded. Sedimentation of the preliminary treatment pond has not yet been a problem, possibly as a result of the close attention paid to construction-related sediment control and site landscaping.

Continuing research on the Hidden River Wetland Treatment Site will include investigations into the wetland's hydrologic interactions with groundwater, analyses of soils and sediments, and continued analyses of water quality at wetland inlets and the outlet.

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EPA Region 5

Lake McCarrons Wetland Treatment System, Roseville, Minnesota

The Lake McCarrons Wetland Treatment System was built in 1985 in Roseville, Minnesota, a suburb of St. Paul. About 85 percent of the runoff in the Lake McCarrons watershed is routed to the wetland for treatment prior to discharge to the lake. The portion of the Lake McCarrons watershed draining to the wetland is approximately 636 acres (258 hectares) in size with 17 percent impervious surface. Normal annual precipitation in the area is about 26 in (66.04 cm). Lake McCarrons is a eutrophic lake with a surface of 81 acres (33 hectares) and a mean depth of 25 ft (7.62 m). In summer the dominant phytoplankton are blue-green bacteria and the lake's deeper waters become anoxic.

The two goals of the project are the improvement of the quality of stormwater runoff entering Lake McCarrons and the restoration of an existing degraded palustrine wetland. A sedimentation pond upstream of the wetland serves both as a moderator of stormwater peak flows to the wetland and as a primary pollutant removal system for water entering the wetland. The baseflow in the pond/wetland system was recorded as between 0.05 and 0.20 ft^3/s (0.0014 and 0.0057 m^3), derived from groundwater inflows including natural springs and some storm sewer leakage. The sediment basin was intended to reduce pollutant and sediment loads to the wetland, allowing the wetland to serve a “polishing” function and to restore some of the original wetland functions.

Low berms (12 to 18 in (30.48 to 45.72 cm) high with 12-in culverts) were installed, dividing the wetland into five consecutive chambered wetlands between the sedimentation pond and Lake McCarrons (see Figures 3-5 and 3-6). An entrenched channel in the wetland, a result of increased runoff volume and velocity due to urbanization of the watershed, was filled. These modifications brought the wetland’s hydrology closer to a natural state and allowed stormwater entering the wetland to spread out as sheet flow through wetland vegetation and over the peat/ mineral soils for greater removal of pollutants. The resulting wetland is described as a palustrine emergent marsh similar to the original marsh with a smaller palustrine scrub/shrub border than that present before construction.

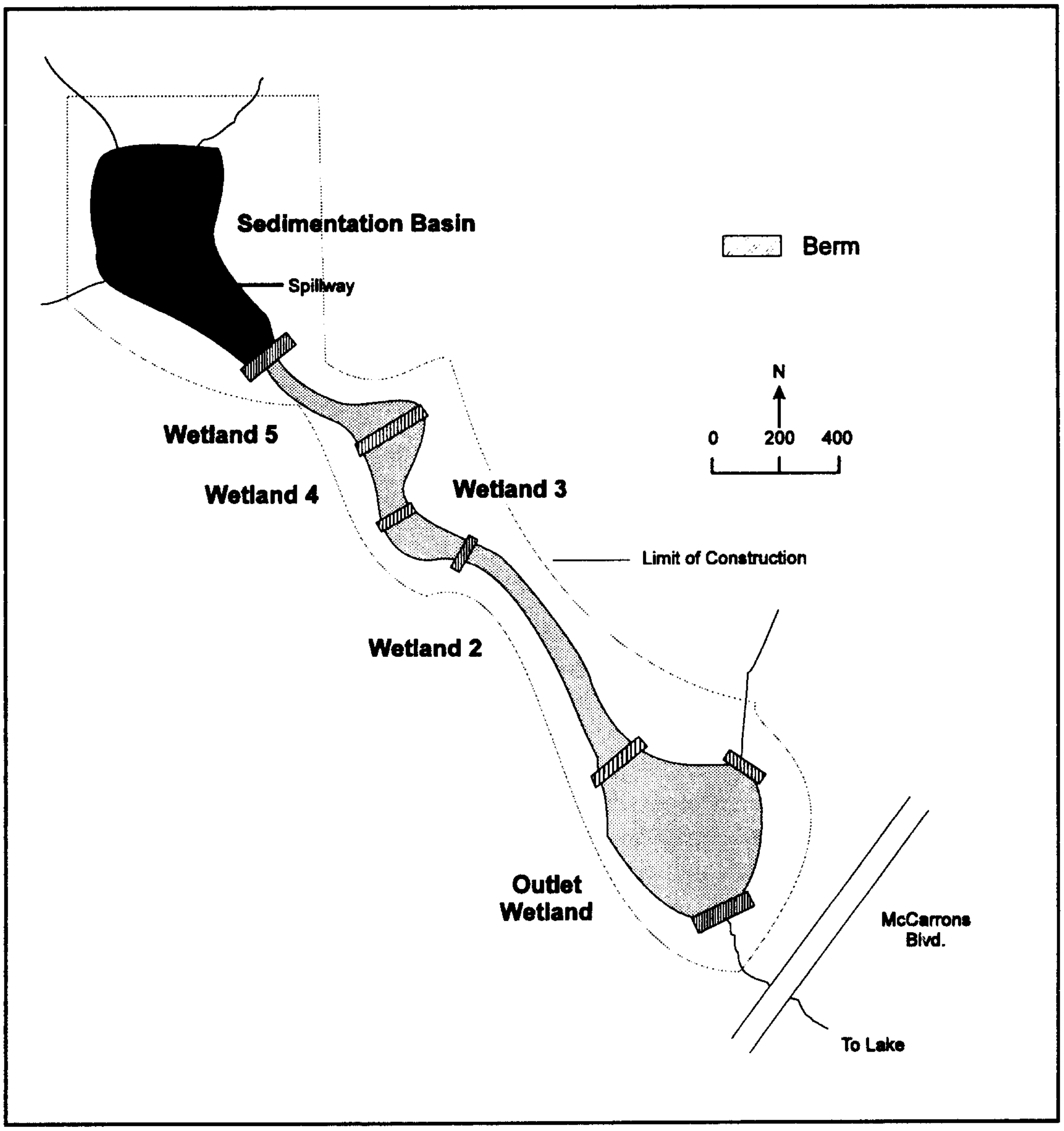

Figure 3-5. Lake McCarrons Wetland Treament System.

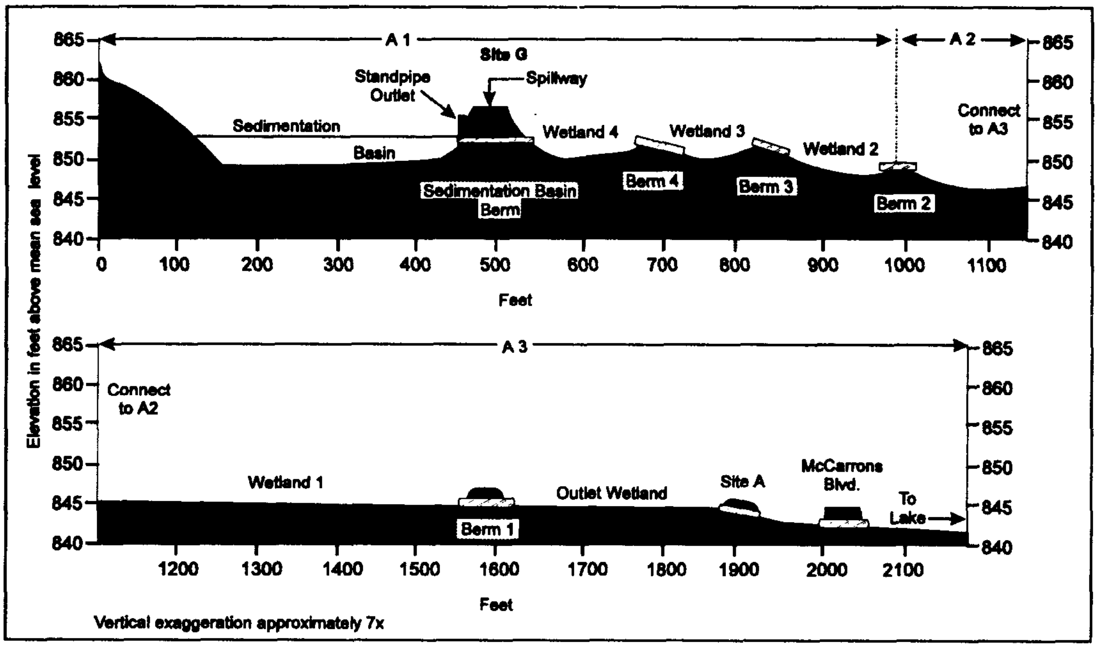

Figure 3-6. Cross section of Luke McCarrons wetland treatment system.

Lower pollutant removal efficiencies were recorded for the wetland than for the sediment pond, probably because of removal of the most easily settled particulates in the pond and the high sorption capacity of newly exposed peat soils in the pond. Table 3-1 shows the results of water quality monitoring for the pond, wetland, and combined system. Although the pond-to-watershed area ratio is only 0.5 percent, the pond performed well in the reduction of pollutants monitored. The pond/wetland treatment system did result in substantial reductions in phosphorus loadings to Lake McCarrons. However, no change in lake water quality has been detected, probably because of the high internal phosphorus loadings that remain in the lake.

Table 3-1. Percent Pollutant Load Reductions: Inflow vs. Outflow Over 21 Rainfall Events

Pollutant	Pond	Wetland	Combined System[a]
Total Suspended Solids	91	87	94
Total Phosphorus	78	36	78
Total Kjeldahl Nitrogen	88	26	85
Total Lead	85	68	90

[a]Some runoff enters the lower wetland with no pretreatment, explaining combined reductions lower than pond reductions.

Among problems encountered are the loss of effective pond treatment when the pond is ice-covered and washouts of wetlands directly below the culverts through berms. Over a 7-year period (1985-1992) there was a loss of pond storage capacity due to sedimentation, with pond depth decreasing from 6 to 2 ft (1.83 to 0.61 m). In retrospect, a design including a drain valve for easier pond maintenance and graveled spillways over wetland berms would have been desirable. Wildlife was described as abundant and the plant community was found to be very diverse in the modified wetland after 3 years; after 7 years cattails *(Typha* sp.) had increased substantially,

Since the completion of the original study in 1988, a sedimentation pond has been added to provide preliminary treatment of runoff entering the lowest wetland chamber. Some road runoff that previously entered the wetland as sheet flow over a grassed area, however, has now been routed directly to the wetland without preliminary treatment. A report presenting the results of a renewed 2-year study on the Lake McCarrons Wetland Treatment System will be completed in the spring of 1997.

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The Phalen Chain of Lakes Watershed Project, Ramsey and Washington Counties, Minnesota

The Phalen Chain of Lakes watershed covers about 23 mi^2 (36.8 km^2) in Ramsey and Washington Counties. It includes five major lakes, 950 acres (385 hectares) of wetlands, and several connecting creeks called county ditches.

The watershed is the land area that drains to the five major lakes-Kohlman, Cervais, Keller, Round, and Phalen. The watershed includes parts of seven communities (Figure 3-7)-Little Canada, Maplewood, North St. Paul, and smaller portions of Oakdale, St. Paul, Vadnais Heights, and White Bear Lake. The lakes follow the ancient bed of the preglacial St. Croix River. The area is considered unique and is heavily used for its recreational resources by local residents and the East Metro area. The Chain of Lakes watershed is also part of a major flyway for migratory waterfowl and songbirds, and it provides significant habitat for other birds and wildlife in an urban setting.

From settlement in the 1850s until World War II, the watershed was dominated by vegetable and dairy farming. Farmers drained wetlands, channelized creeks, and constructed early roads. In the 1970s, construction of Interstate 35E and large commercial areas like Maplewood Mall accelerated urban development in the watershed.

Urbanization has affected natural resources in the watershed in many ways. First, settlement has nearly eliminated the native vegetation of the area, replacing it with buildings, paved surfaces, and lawns. Habitat diversity and the varieties of birds and animals that inhabit the area have been much reduced because of these changes. Non-native species like loosestrife have also gained a foothold in the watershed and become problems.

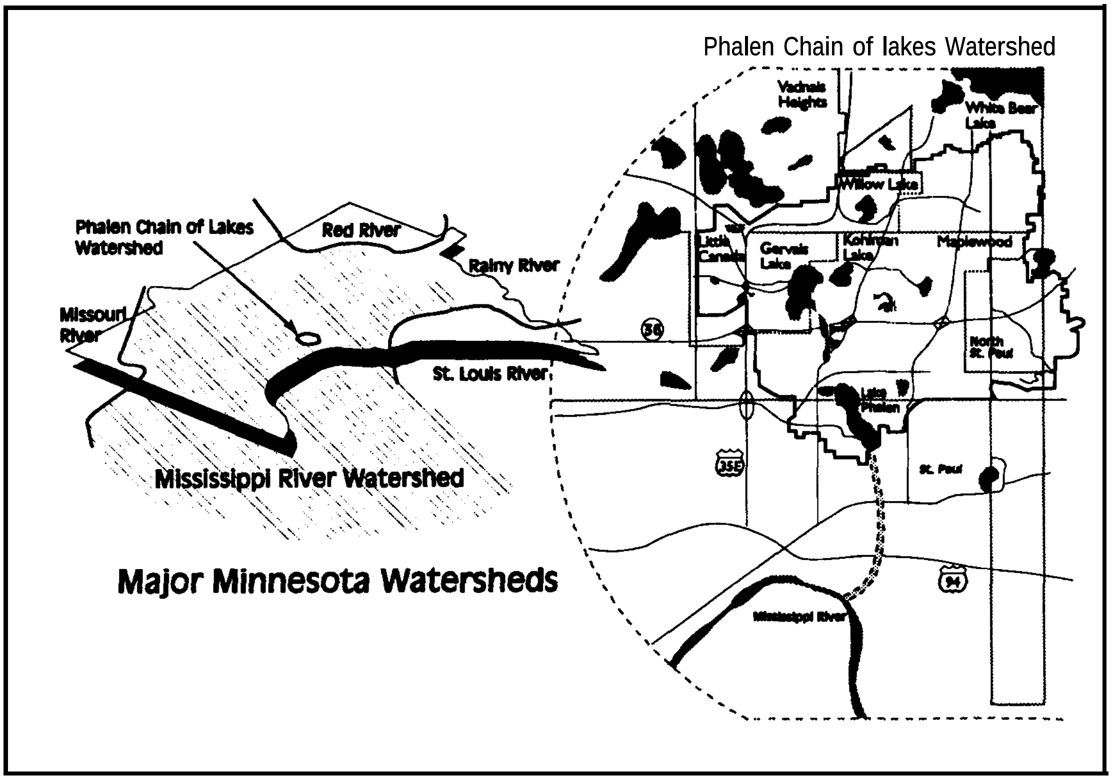

Figure 3-7. Phalen Chain of Lakes watershed.

Second, the natural drainage in the watershed has been altered. Soils, vegetation, and wetlands present at settlement easily absorbed much of the water that fell on the land. Urban development has increased soil compaction, paved surfaces, channelized creeks, and eliminated over half the wetlands in the watershed. These changes cause more water to run off the land at a faster rate, creating flooding and erosion problems.

Higher volumes of runoff carry pollutants and nutrients to lakes, wetlands, and creeks, causing declines in water quality, and a reduction in the quality of fish and wildlife habitat. Algae blooms on area lakes are evidence of these changes. It is apparent that without conscious efforts to manage land and water resources differently, ongoing development in the watershed will continue the following trends:

- Increasing volumes of stormwater runoff, with additional sediments and nutrients transported to wetlands, creeks, and lakes.
- Loss of aquatic vegetation and reduced habitat for fish and other aquatic organisms.
- Increasing fragmentation of upland and wetland habitat and loss of plant and animal diversity
- Loss of open space.

In early 1993, a partnership was formed to address concerns about declining natural resources in the watershed. The partnership included local city governments, developers and businesses, the University of Minnesota, and the Minnesota Department of Natural Resources. The partnership received a grant to develop a comprehensive plan for the watershed. A Steering Committee, including representatives of all interested groups in the watershed, completed the plan in April 1994.

The comprehensive watershed plan includes seven major goals, BMPs, and many recommended action steps to protect, restore, and manage natural resources in the watershed in the short term and long term. Major goals of the seven-point Action Plan for the Watershed include the following:

- Improve, restore, and protect surface water quality.
- Restore, enhance, and protect wetlands and creeks.
- Protect the groundwater resources of the watershed.
- Develop and support a connected system of "green corridors" to protect water resources, enhance fish and wildlife habitat, and provide natural resources recreation and education opportunities.
- Restore and expand forest cover and diverse native vegetation.
- Increase public awareness and involvement in natural resources management in yards, public and private lands, and all of the watershed.
- Establish a local natural resources board to coordinate implementation of the watershed plan.

During the summer of 1994, the Watershed Project partners, local residents, cities, businesses, and others in the watershed improved natural resources through a variety of projects, including the following:

- Developing an innovative BMP to control stormwater in Maplewood. It will let stormwater infiltrate within a neighborhood and eliminate the need for new storm sewers that would empty into Lake Phalen. This neighborhood will serve as a model for stormwater management in other urban areas.
- Working with the City of St. Paul and District 2 community to obtain funding for the Phalen Wetland Park restoration as part of the Phalen Village Small Area Plan.
- Implementing projects to restore aquatic shoreline vegetation, and working with parks departments and landowners to manage vegetation and use BMPs around wetlands and lakes to benefit fish, wildlife, and water quality
- Completing a watershed-wide wetlands plan, based on the functions and values of wetlands in the watershed, that will help the watershed district and local governments set priorities for purchase, protection, or management of wetlands.
- Completing field work to identify the remaining natural areas and prairie fragments, and inventorying open-space areas to assist in development of the "green corridors" network for the watershed.
- Completing restoration projects at the H.B. Fuller Company Willow Lake Nature Preserve to restore aquatic vegetation and other natural communities.
- Developing a workshop for teachers in five local school districts on watershed issues and identifying student projects to benefit natural resources.
- Working with neighborhood and citizen groups on creative plantings and projects to benefit natural resources in parks and residential areas of the watershed.

The Phalen Project Committee will continue to work with local governments, businesses, citizens, and natural resources agencies to identify projects and opportunities to benefit land, water, plants, animals, and local communities.

The Prairie Wolf Slough Project, Chicago, Illinois

The Prairie Wolf Slough is one of several projects aimed at addressing natural resource issues along the 156-mile-long (249.6-km) Chicago River corridor. The 25-acre (10.1-hectare) project involves the ecological restoration of a wetlands/prairie/savanna complex along the Middle Fork of the North Branch of the Chicago River and the creation of an interpretive nature trail.

The key component of the restoration is the creation of a wetland vegetation complex that, in the past, was drained by an agricultural drainage tile system. Sediments and other contaminants used to enter the stream via a gully created by the outlet of the drainage system. After the tiles were removed and the gully was filled, water naturally returned to the floodplain. The restored wetlands help to eliminate sediments, nutrients, and residues from farm chemicals used on the property, which is leased by a local farmer for row crops.

Water drains onto the site from a corporate complex and a shopping center, which contribute pollutants typical of urban runoff, such as lawn chemicals, road salts, and oil and grease. Ponds just downstream provide some physical removal of sediment, but most of the organic toxics and dissolved nutrients are not removed. The project diverts water from the two upstream sources into the wetland system, which provides secondary biological treatment of the runoff. The water from the site will eventually percolate back into the river, but it will have been purified by the restored wetland, absorbing waterborne sediments and nutrients that reach the river. The native wetland vegetation will also function as a filter medium to assist in removal of deleterious waterborne metals.

The restored wetlands will have a beneficial impact during flood events. By restoring a cover of dense native vegetation to the 25-acre (10.1 hectare) parcel, many beneficial wetland functions would be restored. These include an improvement in the retention of precipitation. A dense matrix of native plants would filter and hold more water than would a traditional crop field. Increased water retention time translates into an increased ability for soil water absorption and, therefore, decreased surface erosion.

The restoration will benefit many surrounding jurisdictions. The communities will benefit from the enhanced site aesthetics, improved wildlife habitat, and increased recreational opportunities for walking and nature observation. The parcel of land is a logical link with a proposed riverside trail system and is also a part of a larger greenway that follows the Middle Fork of the North Branch of the Chicago River. This corridor provides vital habitat, foraging sites, and nesting locations for neotropical migratory birds, in addition to providing habitat for migratory waterfowl. Local grade and high schools and a nearby college will also use the site for environmental education activities and the promotion of environmental awareness. The beneficial qualities of the wetlands will also be used by the Friends of the Chicago River to help focus public attention on the importance of water quality, fisheries, wildlife habitat, and open spaces along the river. The volunteer and environmental education components will build interest and a constituency for protecting the river and its upper reaches.

EPA Region 6

Tensas Cooperative River Basin Study, Louisiana

Background

The cumulative impacts of human activities have led to the reduction of bottomland hardwood forests and wetlands, and their associated wildlife habitat, in the Tensas River Basin in northeastern Louisiana. Historically, over 90 percent of the 718,000-acre (290,790 hectares) basin was forested with bottomland hardwoods. Approximately 350,000 of these acres (141,750 hectares) were irregularly to permanently flooded forested wetlands. Today, an estimated 85 percent of these forests have been cleared and converted to row crop agriculture, and the basin now contains only 135,000 acres (54,675 hectares) of bottomland hardwood forests. The accelerated conversion of forestland to cropland during the 1960s and 1970s has resulted in increased environmental and social problems in the basin. The natural ecosystem can no longer sustain acceptable water quality levels, provide adequate flood storage functions, or offer the habitat diversity needed for many wildlife species.

In November 1991, various agencies met with the Natural Resources Conservation Service to devise a strategy for resolving water quality impairment and wetland habitat loss and decline. The group determined that an overall plan was needed for the entire basin to avoid a “piecemeal” approach to protecting the area’s natural resources. As the main sponsor of the study, the Natural Resources Conservation Service realized that for the study to be effective, a broad selection of participants should be included in the process. Participants in the study included the following: U.S. Environmental Protection Agency; U.S. Fish and Wildlife Service; U.S. Army Corps of Engineers; U.S. Geological Survey; U.S. Forest Service; Louisiana Department of Agriculture and Forestry; Louisiana Nature Conservancy; Louisiana Cooperative Extension Service; Louisiana Office of Soil and Water Conservation; East Carroll, Madison, Tensas-Concordia, and Northeast Soil and Water Conservation Districts; Fifth Louisiana Levee District; National Fish and Wildlife Foundation; and farmers of the Tensas Basin. The study began in October 1992.

The objectives of the study were to facilitate and coordinate the orderly conservation and management of the basin’s land and water resources, particularly bottomland hardwood wetlands. Specific objectives include:

- Describe the ecological, economic, cultural, and social resources of the Tensas River Basin.
- Provide a broad-scale analysis of ecological, economic, cultural, and social problems in the basin.
- Describe solutions to the basin’s problems that are environmentally, economically, and socially sound and acceptable to local residents.
- Identify various federal, state, and local agencies and organizations that provide technical and financial assistance for implementing solutions to water and related land resource problems.

Physical Setting

The study area is located in northeastern Louisiana in portions of East Carroll, Madison, Tensas, and Franklin Parishes and encompasses the watershed of the Tensas River from Lake

Providence to its confluence with Bayou Macon. The Tensas River Basin is in a subtropical, transitional climatic region that is affected alternately by cool, dry air flowing southward and warm, moist air flowing northward. Winters are usually mild with an average temperature of 47 degrees Fahrenheit (^{0}F), and the average summer temperature is 81 ^{0}F The average annual precipitation is 55 in (139.7 cm), most of which occurs between December and May.

The Tensas River Basin is located in the Mississippi River alluvial valley, which was formed during the early Pleistocene epoch. Following the glacial retreat of the epoch, the Mississippi River became deeply incised within the basin area, creating a broad, entrenched valley that gradually filled with alluvial deposits. Elevations average from about 100 ft (30 m) above sea level along the northern boundary to less than 50 ft (15 m) along the southern boundary The major landforms resulting from meanders in the course of the Mississippi River can be divided into five categories: abandoned courses, abandoned channels, natural levees, point bars, and back swamps (see Figure 3-8). Forested wetlands can be found in all of the major landforms except the natural levees, which are elevated above the floodplain.

- Abandoned courses are lengthy segments of a river abandoned when the stream forms a more hydrologically efficient course in the floodplain. They can vary from a few miles to tens of miles in length, but they always contain more than one meander loop. The abandoned courses gradually fill in with sediment and are often occupied by a smaller stream or bayou.
- Abandoned channels are cut-off bends of meandering streams, commonly called oxbow lakes. A sediment plug forms in the abandoned channel immediately below the point of cutoff. If the parent stream remains in close proximity, the oxbow quickly becomes partially or wholly filled with fine-grained sediments and is replaced by vegetated wetlands in a few centuries. If the river channel rapidly meanders far away from the oxbow, however, sediment filing is slow and open water conditions often prevail.
- Point bars are crescent-shaped ridges consisting principally of sand and silt on the inside of meander loops as the stream migrates toward the concave bank. As the process continues, a succession of bars can be formed, the height of which can be as much as 10 ft above the mean low water level. The shape tends to conform to the curvature of the channel in which they were created. The low areas between point bars constitute what are known as swales. They develop dense willow growth that traps fine sediments, and in time they are filled with silts and clays. Many of the remaining regularly flooded forested wetlands in the basin occur in swales.
- Backswamps are low, flat, featureless areas bordering natural levees and point bars. Backswamp deposits consist of fine-grained sediments laid down in broad, shallow slackwater basins during stream flooding. Historically, backswamps would remain flooded for months during high river stages and periods of heavy rainfall due to inefficient channels and low gradients. Today, most of these areas have been converted to row crop farms.

The regularly or permanently flooded bottomland hardwood forests are composed of baldcypress *(Taxodium distichum),* drummond red maple (Acer *rubrum drummondii),* swamp blackgum *(Nyssa sylvatica),* and buttonbush *(Cephalunthus occidentalis).* Seasonally and irregularly flooded bottomland hardwood forests are composed of overcup oak *(Quercus lyrata),* bitter pecan *(Carya aquatica),* green ash *(Fraxinus pennsylvanica),* willow oak *(Quercus phellos),* cedar elm *(Ulmus* crassifolia), waterlocust *(Gleditsia aquatica),* boxelder *(Acer negundo),* and hackberry *(Celtis laevigata.*

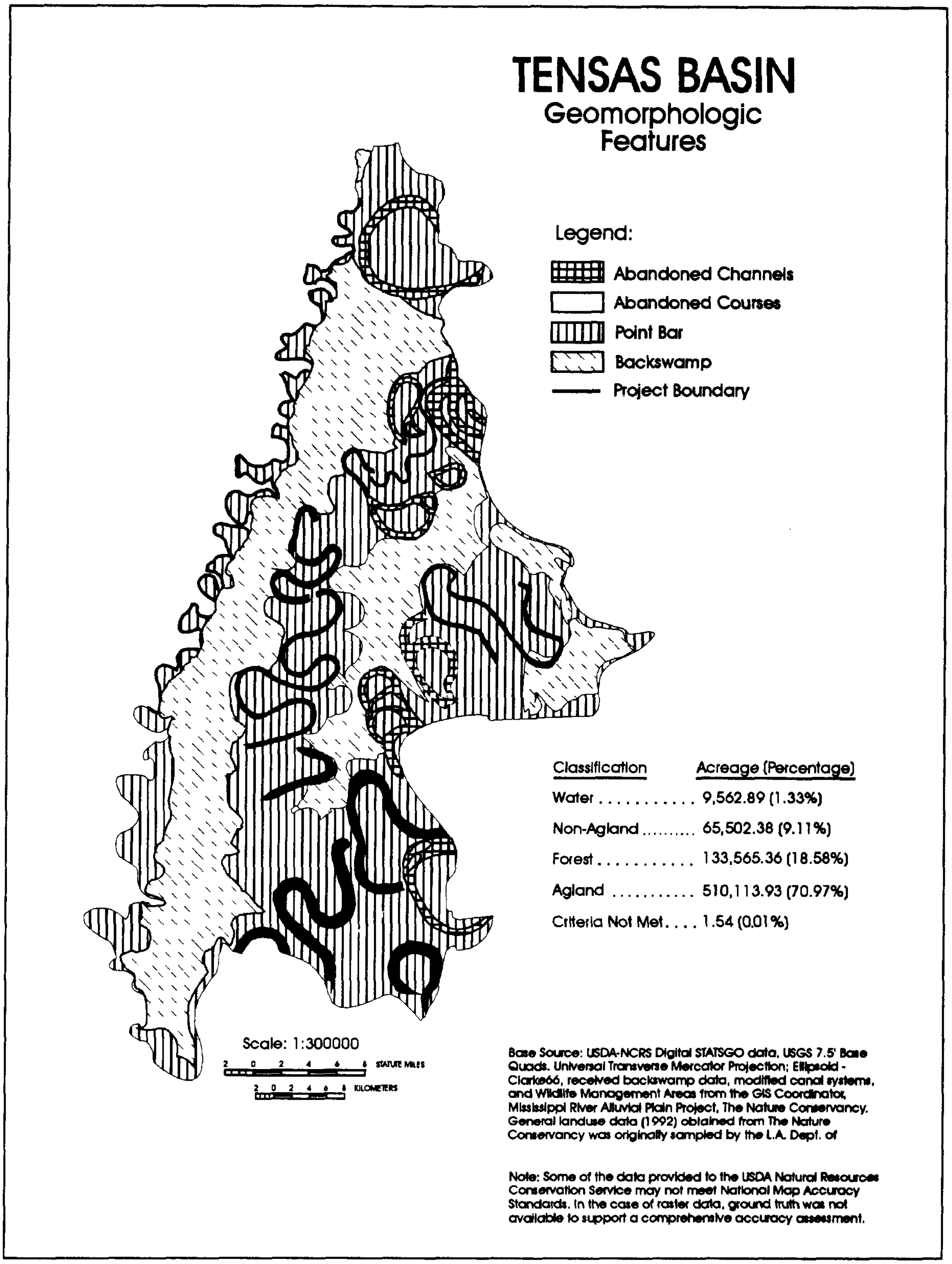

Figure 3-8. Geomorphologic features in Tensas Basin,

The social and economic resources of the Tensas River Basin were also reviewed and incorporated into the study. The economy of the region is based primarily on row crop agriculture (see Figure 3-9). Timber harvesting has diminished since there have been no large reforestation efforts. The area experiences chronic unemployment problems and lack of job diversity and, consequently, has been undergoing an emigration of people in search of job opportunities. For example, prices for farm inputs have increased 46 percent more than prices received for raw agricultural products, and unemployment in the basin ranges from 10.7 to 24.1 percent. These combinations result in fewer dollars being circulated in the local economy and thus reduced job opportunities in the retail and service industries in the rural, farm-based economies.

Problem Identification and Treatment Options

A series of public meetings were held throughout the basin to identify problems and potential solutions. Problems identified include long-term viability of row crop production, bottomland hardwood wetland decline, impaired water quality, flooding, limited recreational opportunities, reduced fish and wildlife habitat, and socioeconomic concerns. Regarding the bottomland hardwood wetland decline, the major sources of problems are habitat fragmentation, excessive sediment loading, and nutrient and pesticide loading. Throughout the analysis and planning process, it became apparent that the problems were usually interrelated. Water quality was also being impaired due to excessive sediment loading and nutrient and pesticide loading, which was reducing the profit margin for the agricultural operations. Limited recreational opportunities and reduced fish and wildlife habitat were tied to the forested wetland decline. Flooding is also a major problem because there are fewer wetlands to provide floodwater storage and control.

Based on the identified problems, two primary methods for addressing these issues were evaluated: BMPs and bottomland hardwood restoration. Due to the agricultural nature of the region, row crop BMPs were determined to be the most effective. Only BMPs deemed by the study group to be cost-effective, efficient, and acceptable to the residents were included in the final plan. Row crop BMPs are categorized as follows: (1) soil management, (2) water management, and (3) nutrient and pesticide management.

Soil Management BMPs

Soil erosion was determined to be linked to many of the problems identified in the basin, including the decline of bottomland hardwood wetlands. Soil particles often act as carriers of nutrients and pesticides, which further add to water pollution problems. Soil erosion can be reduced by maintaining a protective cover of plants or plant residue, reducing the number of tillage operations, and improving soil structure. The following BMPs were determined by the Tensas River Basin study to be the most effective measures in reducing soil erosion: (1) chiseling and subsoiling, (2) conservation cropping sequences, (3) conservation tillage systems, (4) contour farming, (5) cover crop, and (6) crop residue use.

Water Management BMPs

Water management practices are applied in the fields where the crops are grown and at the field edges where water enters and exits a field. BMPs applied in the crop field to facilitate plant . growth and to reduce sediment and water from leaving the fields include (1) land leveling, (2) irrigation water management, and (3) crop row arrangement. BMPs applied to minimize

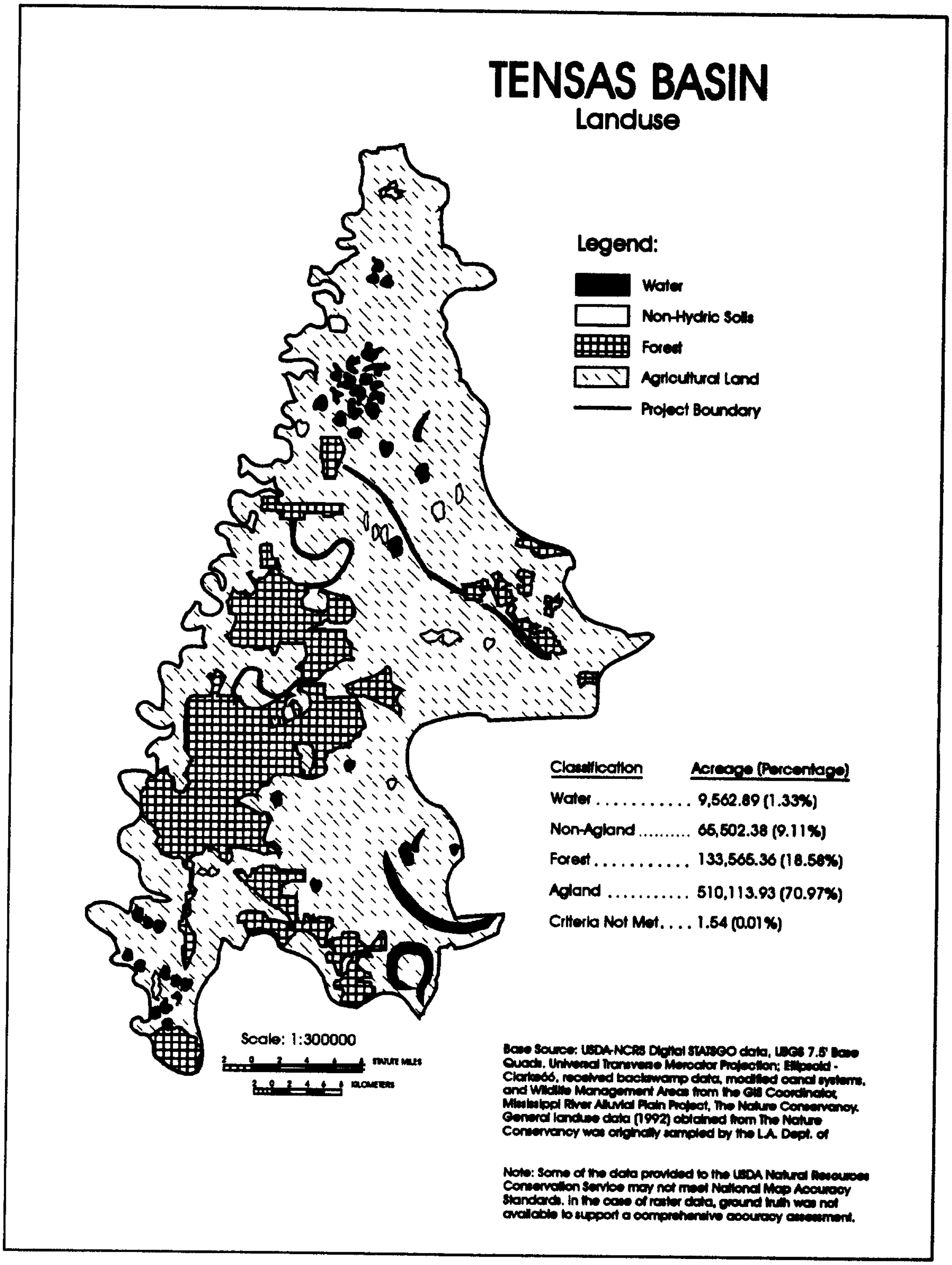

Figure 3-9. Main land uses in Tensas Basin.

environmental impacts before or after water reaches a field are (1) filter strips, (2) grassed waterways, (3) irrigation tailwater recovery, (4) water and sediment control basins, and (5) water control structures.

Nutrient and Pesticide Management BMPs

Nutrient and pesticide runoff is closely tied to soil and water management. However, in many instances excess nutrients and pesticides do not need to be applied. Prudent application of nutrients and pesticides enables the producer to reduce expenses while having a positive impact on the surrounding wetlands. Proper nutrient management requires periodic soil testing and use of fertilization rates within a recommended range. Pesticide management requires the use of field scouting, safe handling and mixing procedures, and nematode assay to determine if and when pesticides should be applied.

Bottomland Hardwood Restoration

Approximately 350,000 acres (141,750 hectares) of hydric soils occur in the Tensas River Basin. On some hydric soils, profitable row crop production might be limited over the long term and therefore the most prudent land use for these soils would be hardwood production because it would allow the floodplain to function naturally Bottomland hardwood restoration would reduce the impacts of flooding and would improve water quality. It would improve fish and wildlife habitat while providing a higher economic return. Although not always considered a BMP to protect natural wetlands, the restoration of the forested wetlands would enhance the existing wetlands by enlarging the resource as well as providing additional buffer zones.

Implementation

The Natural Resources Conservation Service will use the Tensas River Basin Study to develop detailed watershed plans for implementation of BMP measures and to target potential bottomland hardwood restoration sites. Solving the environmental and social problems of the Tensas River Basin will require a concerted effort by private landowners, federal and state agencies, local governments, and organizations. Implementation of land treatment options, to a large extent, is dependent on the voluntary efforts of local landowners. However, by demonstrating that protection and restoration of bottomland hardwood wetlands not only will improve environmental quality but also will provide economic and social benefits for the landowners, this transition should be more easily accomplished. Probably the most beneficial aspect of the basin study was the consensus building. The diversity of the participants ensured that a variety of viewpoints were considered, and the result is a plan that relates protection of bottomland hardwood wetlands to the overall health of the watershed, including the socioeconomic health.

References/Additional Information:

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EPA Region 7

Multi-Species Riparian Buffer Strips, Bear Creek Watershed, Iowa

Background

Most agricultural landscapes are a mosaic of croplands and residences superimposed on areas that were previously natural prairie, wetland, and forest ecosystems. In the Corn Belt of the midwestern United States, most of these natural ecosystems have been cleared for agricultural purposes. In Iowa, for example, 99 percent of the prairie and wetlands have been converted to other uses. Many of the remaining riparian wetland systems are heavily impacted by nonpoint source (NPS) pollution. BMPs in the Midwest that include the protection of riparian wetlands as an objective must also address enhancement and restoration of riparian wetlands. An example of this type of BMP is a multi-species riparian buffer strip (MSRBS) system designed and placed along Bear Creek in central Iowa by the Iowa State Agroforestry Research Team.

The Bear Creek Watershed is located in north-central Iowa within the Des Moines Lobe, the depositional remnant of Wisconsinan glaciation in Iowa. Bear Creek is 2.16 mi (34.8 km) long, with 17.27 mi (27.8 km) of major tributaries. The creek empties into the Skunk River. The watershed drains 18,386.4 acres (7,446 hectares) of farmland, most of which has been subjected to field tile drainage during the last 40 years. About 87 percent of the watershed is devoted to corn and soybean agriculture.

Two different levels of research activity are taking place in the Bear Creek Watershed. The Leopold Center for Sustainable Agriculture's Agroecology Issue Team (AIT) is using the watershed to study the condition of riparian zones at the watershed level. The AIT is developing a model to identify critical riparian reaches along the creek that need protection and restoration. The long-term goal of the project is to help farmers who own land along Bear Creek and other streams to develop riparian zone management systems that protect riparian wetlands and water quality by removing sediment and agricultural chemicals.

The Iowa State Agroforestry Research Team (IstART) has been working on one farm in the watershed to develop the MSRBS model system for use along the critical reaches of Bear Creek. This model has been developed by an interdisciplinary team of researchers with specialists in forage crops, soils, hydrogeology, forest hydrology, forest ecology, wetland ecology, economics, biometrics, wildlife management, and extension. The model can be adapted to other waterways in Iowa and the Midwest.

The MSRBS system is a filter strip 65.62 ft (20 m) wide consisting of three vegetative zones. The first zone consists of four to five rows of fast-growing trees planted adjacent to the stream. The second, or central, zone consists of two rows of shrubs. The third zone, planted on the outer edge of the riparian buffer, consists of a strip of switchgrass 22.97 ft (7 m) wide. The MSRBS design takes advantage of the different aboveground and belowground structures of each species to provide maximum year-round interception of sediment and agricultural chemicals from surface runoff and subsurface water movement. One of the innovative aspects of this design is the use of fast-growing tree species that can be used as a short-rotation woody crop system. These systems can produce biomass for energy in 5 to 8 years and timber products in 15 to 30 years. The frequent harvests help to maintain active nutrient and pesticide sequestering by the woody plant community. The selected species do not have to be replanted for three to four harvests because the species reproduce vegetatively by stump or root sprouts. The large root systems allow very rapid regrowth, which provides continuity in water and nutrient uptake and physical stability of the soil throughout the life of the stand.

The MSRBS systems also include native shrubs, which can provide biomass if harvested and demonstrate coppice regeneration. The shrubs increase species diversity and wildlife habitat, provide yet another rooting pattern that will hold soil, intercept shallow groundwater nutrients, and provide organic matter for soil microbes. Finally, the addition of native prairie grasses such as switchgrass will provide additional species diversity, a very high frictional surface for intercepting surface runoff, and a deep and fibrous root system that will play an important role in improving soil quality.

Study Design

The MSRBS system lies along a 3,281-ft (1,000-m) reach of Bear Creek on a private farm (see Figure 3-10). At this location, the creek is a third-order stream with average discharge rates varying between 10.59 and 49.44 ft^3/s (0.3 and 1.4m^3/s). During the past 5 years, pesticides applied on the farm have included chlomazone, atrazine, cyanazine, and the herbicide EPTC. During the past 12 years, impregnated urea pellets have been applied at the rate of 122.83 lb/acre (134 kg/hectare).

The reach of the creek under study was divided into three blocks: inside bend, outside bend, and straight reaches. Five 295.29-ft (90-m) plots were located within each block. Treatments consisting of three combinations of planted trees, shrubs, grass, and two controls were randomly assigned to the plots within each block. The planted treatments consisted of five rows of trees planted closest to and parallel to the creek with a 5.91-ft (1.8-m) spacing between rows. Different species of trees were used in each of the three treatments. One treatment consisted of a

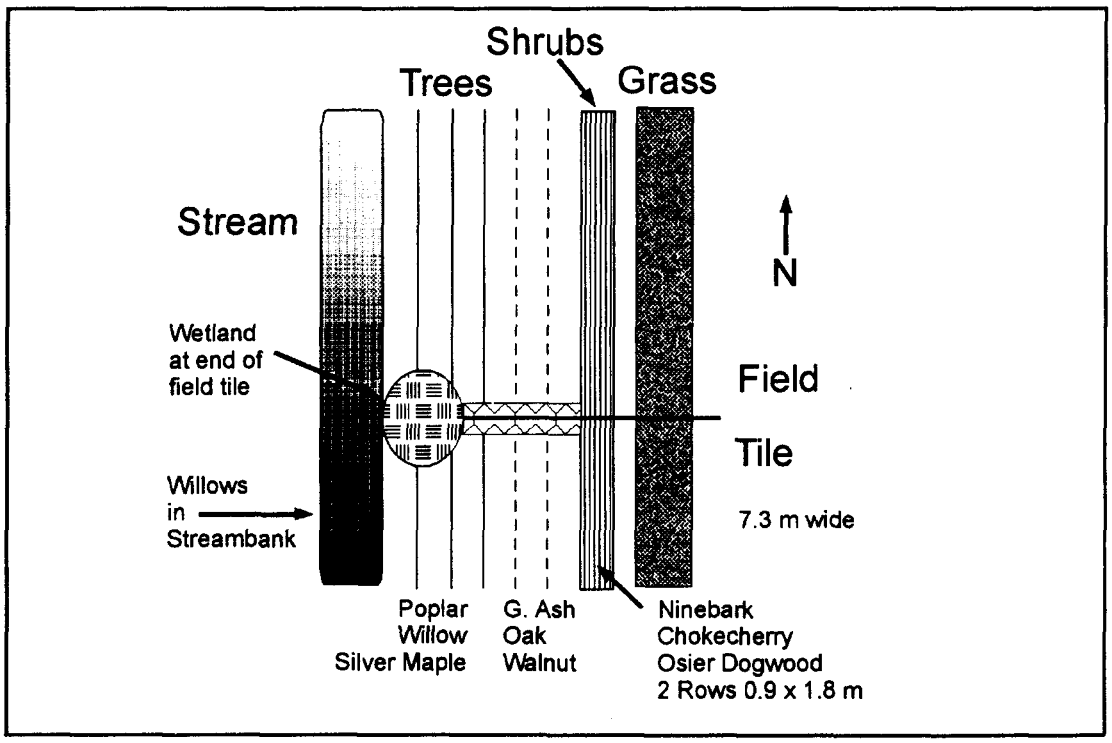


Figure 3-10. Multi-species Riparian Buffer Strip System.

poplar hybrid *(Populus* X *euramericana* Eugenei) that has been extensively tested and is readily available in Iowa. The second treatment contained green ash *(Fraxinus pennsylvanica),* and the third treatment contained a mixture of four rows of silver maple *(Acer succharinum)* with a center row of black walnut *(Juglans nigra).* Upslope from the trees, a row of red-oiser dogwood *(Cornus stolonifera)* and a row of ninebark *(Physocarpus opulifolius)* were planted. The shrubs were planted with 3.94-ft (1.2-m) spacing between rows. Finally, a strip of switchgrass 23.95 ft (7.3 m) wide *(Panicum virgatum)* was planted upslope from the shrubs. Controls consisted of existing pasture grasses. Most trees are being grown on a 6- to 8-year rotation depending on species, and black walnut is being grown on a 45 to 55-year rotation.

The plants for this MSRBS were selected to serve multiple purposes. Those purposes included rapid growth, dense rooting habits, coppice regeneration ability for the trees and shrubs, stiff stems for the grass, cover and food for wildlife, and a potential for being used as biomass for energy The desire was to develop an effective buffer in as short a time as possible to effectively trap sediment and process chemicals and to demonstrate to landowners that a buffer strip with woody plants could be grown rapidly

In the study area, an existing field drain tile was providing subsurface drainage for one of the fields and was discharging untreated water into Bear Creek. An approximately 0.12-acre (500-m^2) wetland was constructed to process field drainage tile water from a 12.11-acre (4.9-hectare) cropped field. The wetland is 1.64 to 3.28 ft (0.5 to 1 m) deep and is surrounded by a low berm. The bottom of the wetland was sealed with clay because of the presence of an underlying substrate of alluvial sand. Organic soil was then placed as the top layer. The agricultural drainage tile was excavated and rerouted to enter the wetland at the point farthest from the creek, forcing the water to travel through the wetland before entering the creek. A gated water level control structure at the wetland outlet provides complete control of the level maintained within the wetland. Cattail *(Typha glauca)* rhizomes were collected from a nearby wetland during the early spring when the shoots had just begun to elongate. The wetland was planted in early June at a spacing of approximately 1.97 ft (0.6 m) on center. Willow cuttings were planted on the stream side of the berm, and native grasses and forbs were planted on the constructed berm for stabilization and to provide vegetation diversity.

Two soil bioengineering structures 262.48- to 328.1-ft (80-to l00-m)-long have been developed as part of the MSRBS system. These structures used live staking and dead tree fascines to stabilize severely eroding banks on the outside stream banks. In the spring of 1992 and 1993, cuttings of dormant willow *(Salix* spp.) 3.28-ft (1-m)-long and 16.41- to 24.61-ft (5- to 7.5-cm) in diameter were pounded into the creek bottom along the toe of the bank and into the stream bank. A dead fascine system using bundles of harvested silver maple was wired together and staked into the bank to provide protection for the cuttings. Most of the cuttings took root and grew. Record floods occurred in the watershed in 1993, and the plantings withstood a record 500-year flood. The resulting plant material reduces the speed of channel flow on the outside of the bend, causes sediment to be deposited in the plant material, and stabilizes the bank against further collapse.

Results

Survival of the trees, shrubs, and switchgrass in the MSRBS has generally been very good. Survival of the three fastest growing tree species was above 87 percent. Black walnut survival was adversely influenced in the second year of growth because of intense grass competition. Ninebark has grown very well, with heights of 6.56 ft (2 m) at the end of 1993. The red osier dogwood has shown mixed growth and has been replaced in spots with nanking cherry *(Prunus tomentosa).* The switchgrass is well established and has produced twice as much biomass as that of the pasture grasses

The MSRBS was evaluated for root biomass production, and preliminary data indicate very high root production (Figure 3-11). This is important because plant roots increase soil stability by mechanically reinforcing soil, and they increase the soil microbial activity that aids in the processing of nutrients and agricultural chemicals. The mixture of trees, shrubs, and grasses provides a dense matrix of roots throughout the soil column, providing greater stability than single-species filter strips.

Water movement through the MSRBS reach of Bear Creek is sampled in the vadose zone (the unsaturated zone of the soil above the water table including the rooting zone), the unconfined shallow aquifer (located in the alluvium and glacial till), the bedrock aquifers, the drainage tiles, and the stream channel. Various kinds of sampling equipment, including piezometers and tensiometers, have been installed to access these different sources of water. Water samples were analyzed for nitrate nitrogen and atrazine. The present protocol calls for monthly sample collections between growing seasons and twice-monthly collections during the growing season.

Although early results do not accurately reflect the full remediation capability of the system when it is mature, the preliminary results demonstrate that a developing MSRBS system can be effective in reducing NPS pollutants. Results for nitrate nitrogen (NO_3-N) and atrazine are shown in Figures 3-12 and 3-13. As can be seen, the NO_3-N concentrations in the MSRBS never exceeded 2 ppm (2 mg/L) even though background levels of NO_3-N exceeded 12 ppm (12 mg/L) in the field. The buffer strip also showed adequate removal rates for atrazine. Data from minipiezometers located at a depth of 9.84 ft (3 m) below the MSRBS confirm that these chemicals are not moving below the buffer strip.

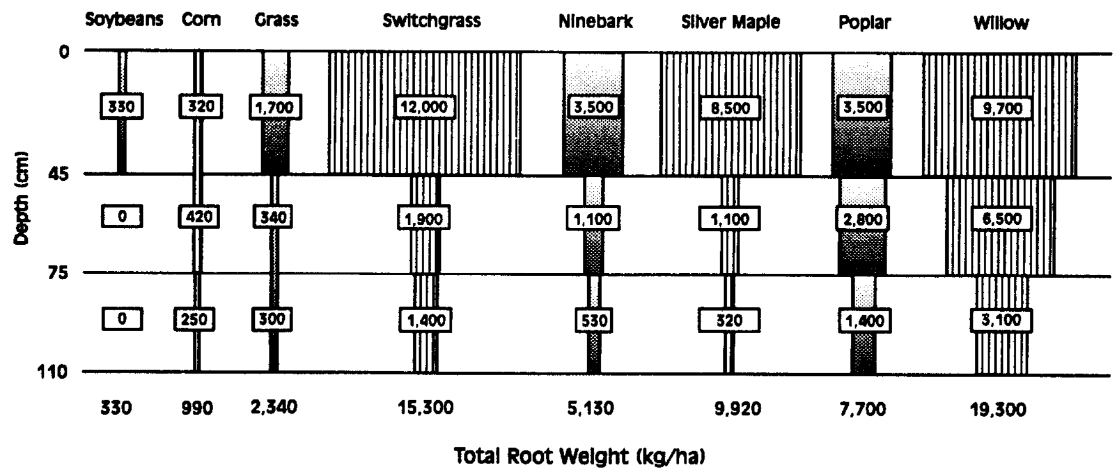
Preliminary data from the first 4 months of operation of the field drainage tile wetland indicate that microbial degradation of NO_3-N is taking place. Measurements are greater than 15 ppm (15 mg/L) at the inflow while measurements are less than 3 ppm (3 mg/L) at the outflow. Under stormflow conditions when residence times are reduced, NO_3-N levels are not as effectively reduced. Based on this initial research, constructed wetland systems can be used to protect existing natural wetlands in agricultural settings. Wetland plant species that can tolerate excessive nutrient loading can be used in the constructed wetland to protect the more susceptible species that occur in natural wetlands.

Visual observations of sediment movement suggest that no significant sediment has moved through the buffer strip since the switchgrass, shrubs, and trees have become established.

Recommendations

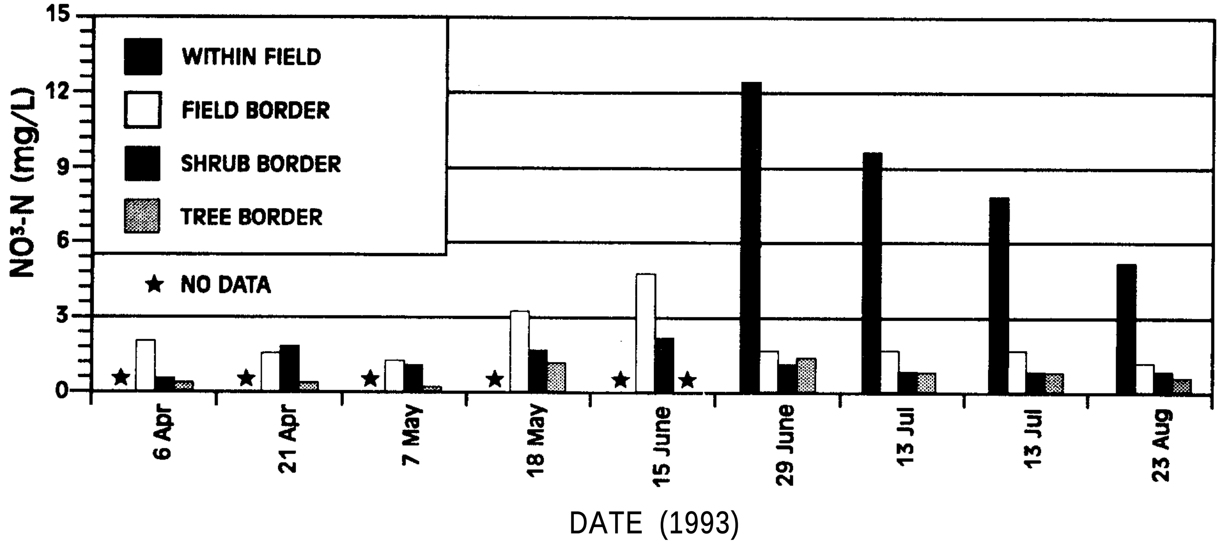
The Iowa State University Agroforestry Research Team has developed preliminary recommendations for Multi-Species Riparian Buffer Strips for Iowa based on their research at Bear Creek. General design recommendations include:

- The general layout should consist of three zones, starting at the stream bank edge; the first zone should include a strip of trees (four to five rows) 29.53- to 32.81-ft (9- to 10-m) wide, the second zone should include a strip of shrubs (one to two rows) 9.84- to 13.16-ft (3-to 4-m)-wide, and the third zone should include a strip of native warm-season grasses 22.97 to 26.25 ft (7 to 8 m) wide.



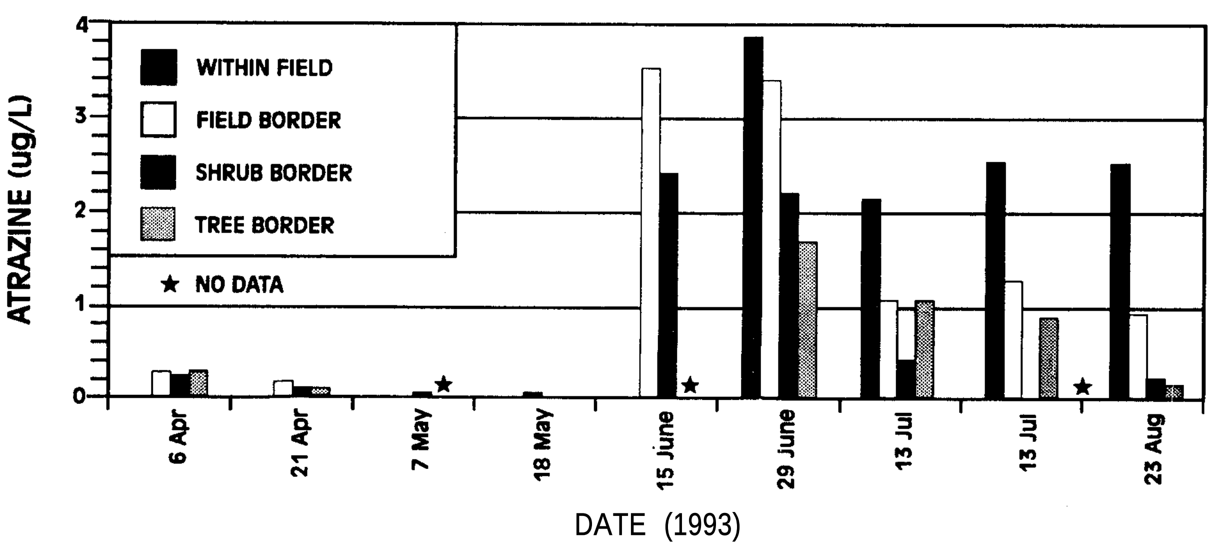
Schultz et al., 1995.

Figure 3-11. Root distribution of buffer strip vegetation by depth and arrangement.



Schultz et al., 1995.

Figure 3-12. Mean nitrate-nitrogen concentrations in the buffer strip.



Schultz et al., 1995.

Figure 3-13. Mean atrazine concentrations in the buffer strip.

- Fast-growing trees are needed to develop a functioning MSRBS in the shortest possible time.
- Rows 1 through 3 in the tree zone should include fast-growing, riparian species such as willow, cottonwood, silver maple, hybrid poplars, green ash, and box elder. Other moderate-growth species include black ash, river birch, hackberry, shellbark hickory, swamp white oak, pin oak, Ohio buckeye, and sycamore. The key to tree and shrub species selection is to observe native species growing along existing natural riparian zones and select the faster-growing species.
- Shrubs should be included in the design to increase biodiversity and wildlife habitat. Possible species include ninebark, red osier and gray dogwood, chokecherry, Nanking cherry, nannyberry, sandbar willow, Bebb willow, peachleaf willow, pin cherry, wild plum, and blackhaw.
- Switchgrass is recommended because it produces a uniform cover and has dense, stiff stems that provide a high frictional surface to intercept surface runoff. Other permanent warm season grass, such as Indian grass, big bluestem, and little bluestem, can be included as long as switchgrass is the dominant species.
- Native perennial forbs may also be part of the mix, especially if they are seeded in clumps.
- If wildlife habitat is an important component of the buffer strip, widths of 98.43 to 295.29 ft (30 to 90 m) would provide a more suitable wildlife corridor or transition zone between the upland agricultural land and wetland/aquatic ecosystem.

Recommendations for tile wetland construction include:

- A small wetland can be constructed at the end of the field tiles by constructing a basin at the ratio of 1:100 (1 acre of wetland for l00-acre drainage). Thebottom of the wetland should be sealed with clay if the soil texture is sandy.
- Clay tile and perforated plastic tile used to drain fields might become plugged by tree and shrub roots in the buffers. Two possible solutions to this problem exist: (1) replace the tile passing through the buffer strip with solid tile or (2) plant a strip of warm season grass above the tile line at a width of 65.62 to 98.43 ft (20 to 30 m) depending on the woody plants that are planted.

Costs for establishment of the MSRBS system have been estimated at $358 to $396 per acre, and annual maintenance costs are estimated at $20 per acre. The establishment and maintenance costs do not include any existing governmental cost-share or other subsidy. Currently, there are several cost-share programs available that will cover up to 75 percent of the expenses. A good contact for information on potential cost-share programs is the local office of the USDA Natural Resources Conservation Service. Overall the MSRBS system seems to function quite well. In addition to protecting riparian wetlands, the MSRBS system offers farmers a way to intercept eroding soil, trap and transform NPS pollution, provide wildlife habitat, produce biomass for on-farm use, produce high-quality hardwood in the future, and enhance the aesthetics of the agroecosystem. As a streamside BMP, the MSRBS system complements upland BMPs and provides many valuable benefits.

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EPA Region 8

Watershed Approach to Municipal Stormwater Management, Fort Collins, Colorado

Introduction

Fort Collins, a city of 92,000 people, is located in a quickly developing area of Colorado known as the Front Range. The city, situated at 5,000 ft (1,524 m), has a semi-arid climate with 14 in (35.56 cm) of annual precipitation and an average of 300 days of sunshine. Due to the pleasant climate, natural areas, and other factors, Fort Collins is experiencing significant growth. This increase in development led the city to create a Stormwater Utility. Within the municipal boundaries, three types of wetland communities can be found. The dominant community is seasonally flooded riparian wetlands consisting of willow *(Salix* spp.), narrowleaf cottonwood *(Populus angustifolia),* plains cottonwood *(Populus sargentii)*, golden current *(Ribes aurem),* and chokecherry *(Prunus virginiana).* The other two wetland communities are seasonally flooded emergent marshes dominated by broad-leafed cattails *(Typha latifolia)* and bulrush *(Scripus* spp.); and seasonally saturated wet meadows consisting of sedges *(Carex* spp.) and rushes *Juncus* spp.).

The Stormwater Utility’s original mission was to create a drainage system that protects citizens from flooding. The Utility typically manages the stormwater system by drainage basin, which is the land contributing stormwater runoff to a particular point, usually a stream. The size of a basin, anticipated rainfall amounts, and the type of land use (i.e., industrial, residential, or natural) are factors used to calculate the need for flood control improvements. With the implementation of the National Pollutant Discharge Elimination System (NPDES) permit program and other programs, water quality became a critical component of stormwater management and required the Utility to take a new look at how drainage systems are designed and managed.

Approach

It became apparent to the city that a drainage system designed to convey flood waters can be planned to meet objectives other than the control of water quantity. For example, drainage systems are typically along riparian wetland corridors, which provide a multitude of functions and values such as wildlife habitat and recreation. Consequently, it became critical to look at the protection and enhancement of these important wetland areas. The city revised the mission statement for the Stormwater Utility to state the “purpose for the utility is to provide stormwater facilities for the drainage and control of surface and floodwaters in order that . . . pollution may be reduced and the environment should be protected and enhanced." Based on this new mandate, the city developed primary and secondary objectives for the Stormwater Utility.

Primary stormwater objectives include:

- Protect Fort Collins from flood waters.
- Protect and enhance water quality in creeks, lakes, and wetlands.
- Protect and restore creeks, lakes, and wetlands as critical wildlife habitat areas.
- Protect water table aquifers from stormwater contamination.

Secondary stormwater objectives include:

- Enhance a sense of community by including citizen participation in protecting local natural areas.
- Create trails to support the use of alternative transportation.
- Promote recreational opportunities associated with trails and natural areas.

To accomplish these objectives, the Stormwater Utility decided to use a watershed management approach as a holistic method to manage stormwater and drainage basins. A holistic approach requires looking at all factors that influence stormwater management, including those factors not typically associated with stormwater management. For example, the Utility realized that alternative transportation has a direct correlation to stormwater quality A reduction in automobile use improves air quality and reduces the amount of pollutants that can be redistributed with precipitation. A reduction in automobile use also reduces the pollutants left on pavement, which can enter the stormwater system through runoff. Carried to its fullest potential, a greater reliance on alternative transportation can lead to a reduction in the amount of impervious surface associated with roads and parking lots, thereby reducing the overall amount of storm runoff contributed to the system.

Another example of looking at the system holistically is addressing the protection of riparian wetland corridors along drainage systems. The riparian corridors provide important benefits such as natural filters of storm runoff, wildlife habitat, and bank stabilization. In addition, stormwater systems along riparian corridors can be considered as potential greenway parks. In times when municipal budgets are limited, integrating park facilities and stormwater systems can be an efficient way of using capital improvement resources.

A final example of how stormwater management and other issues are interrelated is enhancing a sense of community by encouraging citizen participation in protecting local natural areas. By raising the public's awareness of the natural areas along the stormwater system, educational efforts to encourage people not to pollute (for example, encouraging them not to pour chemicals down storm drains) become more effective because people realize the ultimate effects of their actions (for example, they understand where those storm drains discharge). Furthermore, an awareness of why BMPs are used can decrease the likelihood that they will be vandalized.

To begin applying the watershed approach, the Utility divided the urban watershed into three primary and interactive components: land, tributaries, and receiving waters. The urban landscape comprises industrial, commercial, and residential land uses and open space. Tributaries

Table 3-2. Concept Cost Comparison 04 Issues Associated with Watershed Grades

Issue	Grade A	Grade B	Grade C	Grade D
Land Costs	Highest	Intermediate	Intermediate	Lowest
Construction Cost	Lowest	Intermediate	Intermediate	Highest
Opens Space Provided	Highest	Intermediate	Intermediate	Lowest
Development Potential (along drainages)	Lowest	Intermediate	Intermediate	Highest
Maintenance Cost	Lowest	Intermediate	Intermediate	Highest

Next Steps

For the Stormwater Utility to fully implement a watershed approach, the following steps will need to be taken:

- Develop an integrated approach between the various municipal departments (Stormwater, Natural Resources, Parks and Recreation). Clarify implementation roles between departments and eliminate cross purposes and redundancies. The city must realize that the drainage system can play an important role in meeting a variety of city goals, but the city must also understand and agree on a balance between competing objectives. Some of these are:
    - Aesthetics, groomed vs. natural appearance
    - Efficient stormwater flows vs. water and habitat quality
    - Regulation vs. private property rights
    - Service levels vs. cost
- Refine the watershed rating system and develop methods to objectively measure and rank sections of the stormwater system.
- Adopt individual watershed master plans where the master planning of stormwater facilities and natural resource areas, including wetlands, is cooperatively completed through the use of geographic information system (GIS) technology.
- Modify storm drainage design criteria to include a variety of BMPs that protect water quality and wetlands. Include components of the Natural Areas Mitigation *Manual* in the City's storm drainage design criteria.
- Formalize stormwater education efforts and integrate them with other existing municipal and county environmental education programs.

The Stormwater Utility is just beginning to create the framework for an integrated watershed approach to stormwater management. At the municipal level, a successful watershed approach relies on communication and coordination between all departments to provide for a cohesive program. It also requires close communication and input from the local citizens. By preventing pollution on the land, addressing the ecological effects of providing drainage services, and preparing sound hydrologic analysis, objectives related to water quality, public safety, and natural area protection can all be achieved.

References/Additional Information:

McBride, K. 1995. *Stormwater quality: **A watershed approach.*** City of Fort Collins, Colorado.

Lema Nonpoint Source Treatment System, Chatfield Reservoir, Colorado

Chatfield Reservoir, located 15 mi (24 km) southwest of Denver, Colorado, impounds water from the South Platte River drainage, a 2,969 mi^2 (7,719.4 km^2) watershed. The reservoir is a flood control structure built and operated by the U.S. Army Corps of Engineers, and it has become an important recreational facility for the metropolitan region. The developed lower portion of this watershed system is the Plum Creek subwatershed, which is a 438-mi^2 (1,338.8-km^2) drainage area in Douglas County Plum Creek and Chat field Reservoir in the Plum Creek subwatershed are identified in the Denver Regional Council of Governments (DRCOG) regional Clean Water Plan as being affected by nonpoint source (NPS) pollution, primarily high phosphorus loading.

The magnitude of the problem is reflected by the total pounds of phosphorus that reach the reservoir each year. The phosphorus loading of the reservoir is about 53,100 pounds (lb) (24,086 kg) per year from developed land and about 50,513 lbs (22,912.67 kg) per year from undeveloped land. The total maximum allowable load that will not exceed the in-reservoir standard is 59,000 lb (26,762.4 kg). Under normal conditions, about 48,300 lb (21,908.88 kg) of nonpoint-source-derived total phosphorus will need to be removed from the watershed.

In addition to degrading water quality, the high phosphorus loads are negatively impacting the fringe wetlands associated with the reservoir and the riparian wetlands along Plum Creek. The fringe wetlands are seasonally and permanently flooded lacustrine wetland communities with a mixture of broad-leafed cattails *(Typha latifolia)*, hard-stem bulrushes, *(Scripus acutus)*, sedges *(Carex* spp.), and rushes *(Juncus* spp,), The riparian wetlands are seasonally flooded palustrine wetland communities with cottonwoods *(Populus sargentii)*, sandbar willows *(Salix exigua)*, and chokecherries *(Prunus virginiana)*. Excessive phosphorus loads are allowing pollution-tolerant and invasive species to take over and decrease plant biodiversity. Eutrophication of the reservoir is promoting algal blooms, which are shading out submergent wetland species.

The Chat field Basin Authority management program has identified many potentially usable BMPs that could reduce phosphorus loading and offer ancillary benefits such as protection of existing natural wetlands. The problem facing the Authority is predicting the effectiveness of these BMPs. The Authority wants highly effective, low-cost, and easily maintained BMPs for the watershed nonpoint source control program. The placement of small BMP structures at every site of urban development that generates nonpoint source pollution appears to be a very costly option. Therefore, a pilot project was selected to evaluate the effectiveness of a low-cost, biologically based system.

Lemna System

A private corporation has developed a natural biological treatment process that uses aquatic plants (duckweed) to assimilate nutrients and reduce pollutants in a pond environment. Duckweed *(Lemna* sp.) is a small floating plant commonly found in many lakes, ponds, and slow-moving streams. It consists of one or more leaves (called fronds) but has no visible stem. Over 35 species of duckweed grow worldwide in a variety of climates. Duckweed is an extremely fast-growing plant that reproduces primarily by vegetative processes. The biomass can double in less than 18 hours under optimal conditions. In Colorado conditions, the biomass is anticipated to double in about 72 hours. Seasonal changes in weather and sunlight affect pond temperature and thus the growth of duckweed. Optimum growth is achieved at 68 ^{0}F (20°C) to 86°F (30 ^{0}C). Lemna is semi-tolerant of cold temperatures and will continue to grow slowly at temperatures near 44 ^{0}F (7 ^{0}C). Nitrogen, phosphorus, and trace metals are needed to support the growth of duckweed, with optimum growth possible when there is a balance of available nutrients. Low levels of either nitrogen or phosphorus result in starved plants.

The use of Lemna has proven effective as a wastewater treatment nutrient removal system, with the added benefit of reducing metals, biological oxygen demand, and total suspended solids along with its constituents. The resultant effluents have low phosphorus concentrations (below 1 ppm (mg/L)). The by-product of the Lemna process is plant tissue, which has been used as a food supplement for feedlots and as a compost product. The Chatfield Basin Authority has implemented a pilot system using *Lemna* to determine the system's effectiveness in removing nutrients from Plum Creek before it enters Chatfield Reservoir. The pilot system is under evaluation for 1 year to assess water quality benefits; it will then be monitored longer to assess the effectiveness under various hydrologic loading conditions naturally encountered in the Plum Creek subwatershed.

The main pollutant removal pathways are a combination of plant mat uptake and precipitation. Management of the duckweed system for phosphorus removal maximizes growth of the plant mat. The primary method for maximizing growth is mat density management. Mat density management uses harvesting of the biomass to optimize the uptake of phosphorus. A young duckweed plant population tends to have higher phosphorus uptake rates and grows faster than an older plant population. Additionally, the water column can contain sufficient concentrations of ions, which promote precipitation of insoluble salts. Some of the phosphorus, for example, will precipitate and settle as calcium phosphates. The duckweed also reduces algae growth by not allowing light into the water. Algae can contribute to increased total suspended solids within the water and subsequent effluent discharge.

The treatment system consists of three primary components:

- A patented floating-cell system that can be adapted to a wide variety of pond configurations. This allows the system to be adapted to existing pond structures (e.g., gravel operation ponds). The floating cells are designed to contain and control locally available *Lemna* plants.
- An on-shore control unit and automatic sensing probes provide nutrient circulation and assess chemical balance within the pond structure.
- An aquatic harvester is used to inoculate, distribute, and harvest *Lemna* plants from the pond surface. A single harvester can be used on many ponds to improve the cost effectiveness of the system.

The advantages of the Lemna system over other more conventional biologically based BMPs include:

- Marginal, poor-quality lands can be selected for a site.
- The system can be designed to accommodate the available site.

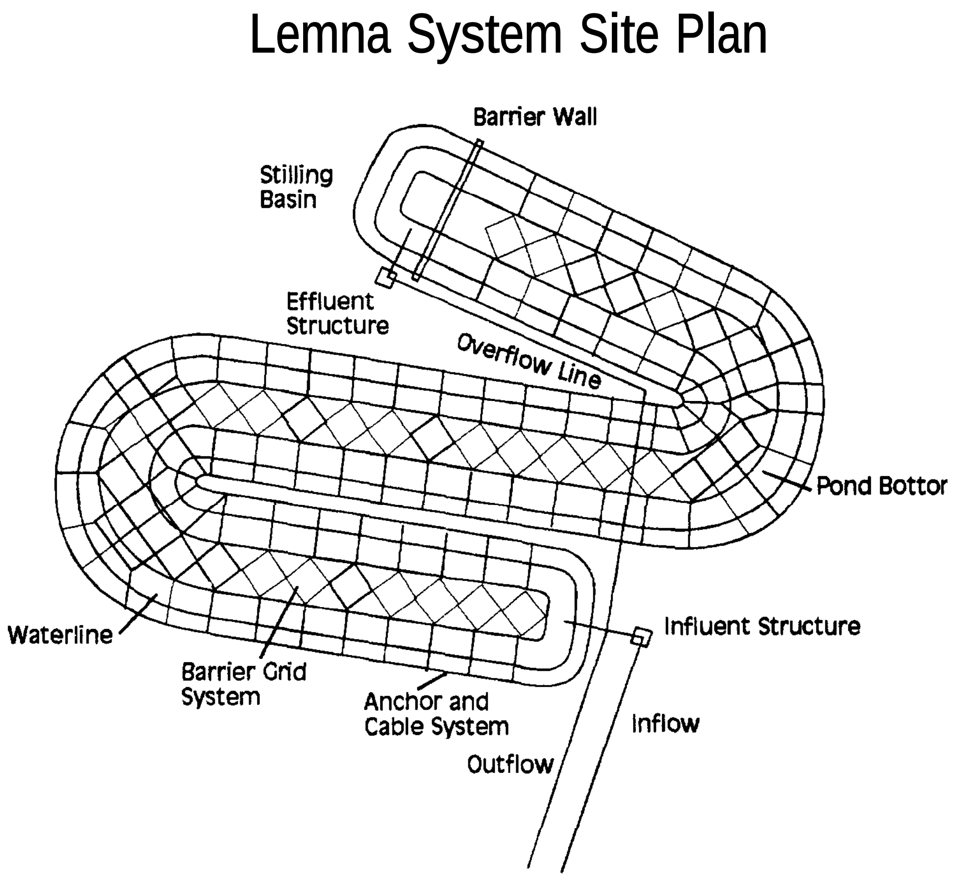
- The system hardware is simple and durable, which reduces future maintenance costs.
- The by-product can be used as a high-protein food supplement for feedlots.
- The by-product can be composted and land-applied for beneficial reuse.

The disadvantages of the Lemna system over other more conventional biologically based BMPs include:

- An energy source is required for the various pieces of hardware, including the pump and aquatic harvester.
- Personnel are required to maintain and operate the system.

Pilot Scale Description

The Chatfield pilot system is located off-channel of Plum Creek with protective banks to keep the system from being impacted by floods. The system is designed as a S-shaped pond or lagoon. The final pond is about 45 ft (13.72 m) wide and 600 ft (182.88 m) long, with an average depth of 5 ft (1.52 m) and maximum surface acreage of 6.2 acres (2.5 hectares) (Figure 3-15). A small stilling basin was created near the outflow by placing a sandbag barrier across the pond with a flow-through pipe and float release valve. Discharge into the system and outflow from the system pass through similarly designed concrete boxes. These boxes have built-in flow weirs for measuring flow.



DRCOG, 1994.

Figure 3-15. Lemna nonpoint source treatment system.

The pond system is lined with a 20-mil PVC liner. A set of barriers was installed as shown in Figure 3-15. This barrier system was anchored to the sides of the pond with a cable system and was designed to keep the duckweed plants evenly distributed across the pond's surface. A diversion structure was installed in Plum Creek. The system inflow sump tank and the return outflow line were installed immediately above and below the diversion structure, thereby preventing any drying of the stream as a result of this diversion. A small pump with a timer lifts the water from the sump tank to the pond. Return flow relies on gravity, and the water is discharged directly into Plum Creek below the point of diversion.

The final cost for the pilot project was $210,510, which was $42,510 more than the original estimate for the project. The Chatfield Basin Authority anticipates spending an additional $7,500 over the next year to complete its evaluation of the system as a BMP.

Operation and Results

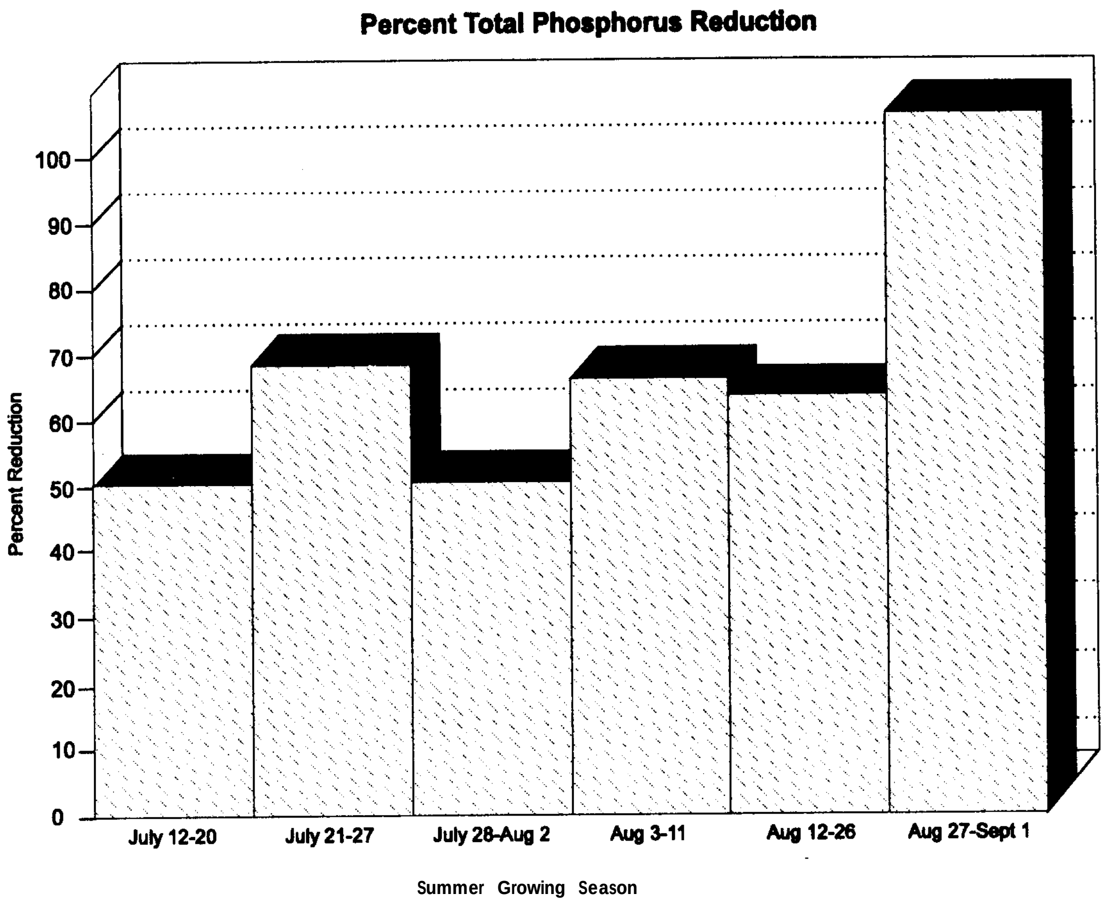
Inoculation with native duckweed is the primary operation necessary for successful start-up of the system. Sources of duckweed included backwaters of streams and small ponds near Chatfield Reservoir. The Chatfield system start-up in April 1994 did not produce the desired plant densities, and additional plant material was collected and added to the system in April and May 1994. It appears that a low-nutrient duckweed system is much harder to inoculate and will require a longer start-up period. Consequently, additional duckweed plants were added to the system and undesirable algae were harvested.

Low or unbalanced concentrations of nitrogen or phosphorus can limit growth of duckweed. Typically, this is not a problem for duckweed systems that rely on wastewater but seems to be a problem with NPS pollution systems. Plum Creek was experiencing unusually low nitrogen loading rates during the start-up period, which was resulting in poor duckweed growth. Nitrogen was applied by spraying fertilizer onto the duckweed mat to compensate for nitrogen deficiency.

Hand harvesting was used on the pilot system, although large systems usually use a mechanical harvester. An investigation was made of local markets and disposal options. The plant tissue is not classified as a biosolid, and the Chatfield Basin Authority has identified no apparent disposal problems. The biomass can be composted onsite by mixing it with a carbon supplement such as sawdust or wood chips.

Flow rates through the pilot duckweed system were designed at 23 days. The low stream flows in Plum Creek and low nutrient loads required changes to the flow rate through the system. The flow rate was shifted to a l0-day retention time. Based on a l0- day retention time and a typical growing season extending from April to November, the duckweed system can process about 24 pond volumes per year. Monitoring data at the end of the first growing season suggest that the flow rate could be reduced to 5 days. Flow rate evaluation studies will be done by the Chatfield Basin Authority during the 1994-1995 monitoring program.

The preliminary data from the 1994 growing season monitoring program show that the system is reducing total phosphorus on the average of 71 percent per pond volume with an average influent concentration of 0.1 ppm (0.1 mg/L) and a discharge concentration of 0.02 ppm (0.02 mg/L). The range of total phosphorus removal varied from 50 to 98 percent as shown in Figure 3-16. The preliminary water quality data suggest that a duckweed system used as a BMP could achieve consistent 50 percent removal of nonpoint source phosphorus as required in the Chatfield Basin Control Regulation.



DRCOG. 1994.

Figure 3-16. Range of total phosphorus removed by the Lemna system.

Conclusion

Although results of this project are preliminary, it appears that a scaled-up Lemna system could function as a regional water quality enhancement and wetland protection system by processing stream flows directly from Plum Creek or the South Platte River. The next steps the Chatfield Basin Authority will take with the Lemna project include detailed water and biological quality monitoring, cost-effectiveness evaluation of the system, a study of harvest material disposal options, other research applications, and implementation of a full-scale nonpoint source management system. When completed, the study will be submitted to the Urban and Construction Subcommittee of the Colorado Nonpoint Source Task Force for consideration as a Colorado Best Management Practice.

References/Additional Information:

DRCOG. 1994. *Lemna nonpoint source treatment system: Final report and operation and* maintenance manual. Denver Regional Council of Governments, Denver, CO.

EPA Region 9

Lincoln-Alvarado Project, Union City, California

A piece of property in Union City, California, consisting of 69 acres (28 hectares) of upland habitat and approximately 12 acres (4.8 hectares) of wetland habitat, was proposed for a multiphase warehouse/distribution complex. A section 404 permit was required from the Corps of Engineers, San Francisco District, because 12.5 acres (5 hectares) fell within section 404 jurisdiction. The landowners proposed that 9 acres (3.6 hectares) would be developed and the remaining 3 acres (1.2 hectares) would be incorporated into a 5-acre (2-hectare) onsite mitigation area consisting of one-third marsh, one-third seasonal wetland, and one-third upland. After extensive review by the Corps and other federal agencies and negotiation with the applicant, the project was approved with the following requirements that included pretreatment of runoff: (1) rainwater flow from the roofs of major buildings would be directed to grease/sediment traps and then to wetlands, (2) 12 acres (4.8 hectares) of jurisdictional wetland would be preserved, (3) a 1.18-acre (0.47-hectare) buffer would be established, and (4) funding for the permanent maintenance would be provided by assessments on a ‘benefits district” of all properties in the subdivision (Association of Bay Area Governments, 1991).

References/Additional Information:

Association of Bay Governments. 1991. San *Francisco Estuary Project. Status and trends report on wetlands and related habitats in the* San *Francisco* Bay Estuary. Third draft. Prepared under cooperative agreement with U.S. Environmental Protection Agency. Agreement **No.** 815406-01-0. Association of Bay Area Governments, Oakland, CA.

EPA Region 10

Riparian Area Wetland Restoration Project, Sawmill Creek, Idaho

Sawmill Creek is located in the Bureau of Land Management’s (BLM) Big Butte Resource Area, 37 mi (59.2 km) northwest of Howe, Idaho. Sawmill Creek resides within a 200,000-acre (81,000-hectare) watershed that drains a high-elevation (6,400 ft (1,950 m)) desert valley surrounded by mountains. Soils are derived from alluvial deposits consisting of limestone and volcanic debris. The climate is semiarid, with hot summers and cold winters. Annual precipitation averages 100 to 114 in (254 to 289.56 cm); 66 percent occurs as snow. Cattle grazing is the primary land use activity along the creek, and fishing and camping activities are steadily increasing.

Prior to 1986, the combined effects of flooding, wildfires, channelization, and fall grazing had degraded the riparian area along Sawmill Creek, causing bank instability, lateral degradation of the stream channel, and reduced fish habitat. In response, the BLM and the Idaho Department of Fish and Carrie (IDFG) initiated the Sawmill Creek Project to restore the riparian zone and improve channel morphology Specific project objectives included (1) improved growth, vigor, and regeneration of the riparian zone; (2) increased bank stability; (3) increased fish populations; and (4) improved channel morphology.

Pretreatment surveys conducted by the BLM and the IDFG enabled these agencies to identify critical areas and develop a riparian restoration plan. Approximately 8 mi (12.8 km) of Sawmill Creek were treated by implementing the following BMPs.

- Installation of 8 mi (12.8 km) of fencing along the creek, creating an upstream and a downstream riparian pasture. The upper 5 mi (8 km) of riparian pasture has been fenced-off and allotted for spring grazing only, while the lower 3 mi (4.8 km) has been excluded from grazing for up to 15 years. The previous grazing plan allowed season-long grazing throughout the riparian zone.
- Establishment of upland troughs for off-site livestock water. Planting of willow and cottonwood cuttings in the lower half of the riparian pasture.

Photodocumentation was effectively used to monitor habitat improvement in the treatment area. Project monitoring and evaluation included (1) established photo points, (2) reconnaissance inventories every 3 years, (3) a willow survivability inventory, (4) infrared aerial photographs of the site to be repeated every 10 years, and (5) water quality sampling. The BMP implementation resulted in increased bank stability in both riparian pastures and expanded natural riparian vegetation, especially onto gravel bars. However, survival of willow and cottonwood plantings has been poor. Beavers have moved back into the area, and fish habitat appears to have improved. Posttreatment response has been slower on the lower pasture (compared to the upstream pasture) due to greater channel instability and pretreatment degradation.

Funding for the restoration came from mitigation money from the Little Lost River Diversion Project supplied by the BLM, USDA Soil Conservation Service, and Butte Soil and Water Conservation District. Total project costs amounted to $90,000.

References/Additional Information:

Connin, S. 1991. *Characteristics of successful riparian* restoration *projects* in *the Pacific Northwest.* EPA 910/9-91-033. U.S. Environmental Protection Agency Region 10, Seattle, WA.

Sublett Creek Restoration Project, Idaho

Sublett Creek is located within the Burley Ranger District on the Sublett Cattle Allotment in Sawtooth National Forest, approximately 55 mi (88 km) southwest of Burley, Idaho. The Sublett drainage encompasses approximately 917 acres (371 hectares) of high desert habitat and is intercepted at its base by an irrigation reservoir. Local topography consists of moderately dissected mountains; soils are derived from limestone. The local climate is frigid with 17 in (43.18 cm) of precipitation annually; 80 percent occurs as snow. Sublett Creek drains U.S. Forest Service (USFS) land except for the lower half mile (0.8 km) above Sublett Reservoir, which is on private land. Because Sublett Creek maintains a popular cold-water fishery, recreational use is heavy.

By 1979, impacts from cattle and camping along Sublett Creek had changed the natural composition of streamside vegetation from desirable riparian species to Kentucky bluegrass, thistle, and other undesirable weeds. The creek had widened, becoming more shallow. Willows were absent along several sections of the creek. Stream bank stability had decreased, increasing instream sediment loads and reducing gravel beds available for spawning trout. In addition, cattle were dying (from bloating) after grazing on watercress growing along Sublett Creek. In response to these disturbances, the USFS and the Idaho Department of Fish and Game (IDFG) surveyed the stream to inventory fish habitat and developed measures to protect and restore the riparian zone; the USFS conducted a riparian habitat survey Both surveys indicated that the drainage had been severely damaged. To protect and enhance the creek, the USFS initiated the Sublett Creek Restoration Project. Specific project objectives included (1) reducing cattle losses, (2) reducing the impact on canyon bottoms and riparian areas from cattle grazing, (3) stabilizing the stream channel, (4) reducing siltation, and (5) improving fish habitat.

A new grazing allotment management plan (AMP) was developed in 1983 in conjunction with the grazing permittee. The old allotment plan consisted of a rest rotation system in which cattle were allowed to remain in a unit season long. The new AMP consists of a modified four-unit rest rotation system with a 5-year rotation. Each of the units is rested 1 year out of 5 except along the north fork of Sublett Creek, which is rested 2 years out of 5. Grazing on this section is now permitted only in the spring. Other BMPs included, (1) establishment of stream bank protection structures along unstable portions of the creek (willows were planted, but survival has been poor), (2) construction of several drift fences, (3) installation of log dams to create downstream pools, (4) installation of two cattle troughs on upland sites, and (5) improvement of permittee herding and salting practices.

Posttreatment monitoring (since 1987) by the Sawtooth National Forest Riparian Team includes (1) sampling to obtain cross section measurements, (2) green line measurement, and (3) measurement of woody-species regeneration within the watershed. Photo points were established prior to treatment and have been monitored since.

Since implementation of the new AMP, water quality and habitat in Sublett Creek have improved and the area also looks better. Posttreatment improvements include (1) improved quality and quantity of spawning gravel, (2) increased stream bank stability (3) increased productivity of riparian meadows and forage, (4) improved flow duration, (5) narrower and deeper stream channels, and (6) decreased cattle losses. Monitoring from 1987 to 1990 indicates that improvements are not continuous throughout all portions of the creek (Chard, 1991). Drought conditions over the past 5 years might have contributed to the slow recovery on portions of Sublett Creek during the last few years.

Funding for the project was provided by the USFS and the Sublett Cattle Allotment Grazing Association. Project costs were split equally between these organizations; total costs amounted to approximately $70,000, $10,000 of which was invested in the riparian zone.

References/Additional Information:

Chard, Jim. U.S. Forest Service, Burley, ID. Personal communication. July 1991.

Connin, S. 1991. *Characteristics of successful riparian restoration projects in the Pacific Northwest.* EPA 910/9-91-033. U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Bear Creek Restoration Project, Crook County, Oregon

The Bear Creek watershed is located southeast of Prineville, Oregon, in Crook County The watershed drains to the west from its origin in the Maury Mountains in the Ochoco National Forest. The Bear Creek watershed drains approximately 55,500 acres (22,478 hectares) of rangeland habitat; elevations range from 3,400 to 5,532 ft (1,036 to 1,686 m). Local topography consists of rolling hills and valleys intersected by steep basaltic ridges and incised drainages. Soils are derived from Columbia River basalt and volcanic ash. The climate is semiarid with 12 in (30.48 cm) of precipitation annually; 40 to 60 percent occurs as snow. Approximately 75 percent of the watershed occupies public lands managed by the BLM, and the remaining 25 percent is owned by cattle ranchers. The primary land use activity is cattle grazing.

Since the 1860s intensive cattle grazing in the Bear Creek watershed had degraded riparian areas along Bear Creek, reducing woody riparian species, lowering the water table, destabilizing stream banks, and increasing instream sedimentation. Fire suppression on upland sites, coupled with lowered water table levels permitted juniper to invade the watershed and replace native herbaceous species, resulting in large areas of bare, erosive ground and reducing available forage. Subsequent to these changes, heavy flooding and overland storm flow within the watershed accelerated erosion and resulted in heavy sediment deposition in Prineville Reservoir and the Crooked River. To control and reduce these impacts, the BLM initiated the Bear Creek Restoration Project. Project objectives included (1) reducing juniper populations and replacing them with herbaceous species, (2) increasing infiltration of precipitation into the soil, (3) stabilizing stream banks, and (4) increasing native riparian vegetation and raising the stream-bottom.

The Bear Creek Project involved 55,490 acres (22,473 hectares), of which 41,260 acres (16,710 hectares) were administered by the BLM and funded from 1972 to 1978. Juniper trees were cut on upland sites (approximately 14,000 acres (5,670 hectares)). Then prescribed burns were used to inhibit further juniper invasion and to aid establishment of herbaceous species. Thirty mi (48 km) of pasture and enclosure fencing was installed on both upland and riparian sites, enclosing approximately 2.25 mi (3.6 km) of riparian area. In addition, 16 mi (25.6 km) of juniper riprap was placed along banks on Bear Creek and several of its tributaries, sediment catchment dams were installed in the creek to raise the creek bottom, springs were developed on upland sites for livestock watering, and a new allotment management plan (AMP) was developed to reduce the impacts of grazing on riparian areas. The old plan allowed season-long grazing on a rest rotation basis. Under the new plan, allotments were divided into a greater number of pastures and a deferred grazing system (20-day rotation period) was used. Crazing permittees and local landowners constructed the pasture fencing and also installed some riprap.

Monitoring activities included (1) photo points on riparian and upland sites, (2) soil surface factor transects to rate erosive potential, (3) macroinvertebrate analysis, (4) cross section stream channel measurement, (5) riparian habitat inventories, (6) stream channel evaluation, and (7) water quality sampling.

Project successes resulted from the watershed approach adopted by the BLM to reduce sedimentation and restore the health of the entire drainage. Upland juniper populations have been effectively reduced, and herbaceous species are more prevalent. As a result, less bare ground now exists, erosion rates have declined, and water absorption has improved, as evidenced by the appearance of new springs. Seventeen mi (27.2 km) of stream now support vigorous riparian growth, bank erosion has declined, and sediment deposition behind the catchments has controlled stream incision by elevating the stream bottom. The new AMP has provided sufficient protection of the riparian areas to allow their regrowth. In addition, forage productivity has increased from 70 to 340 animal unit months (AUMs). An AUM is defined as the amount of forage required to maintain a mature l,000-lb (453.6-kg) cow or the equivalent for a l-month period (USEPA, 1993).

The BLM funded the project with $650,000. Additional costs were borne by private landowners and livestock grazers in the watershed.

References/Additional Information:

Connin, S. 1991. Characreristics *of successful riparian restoration project in the Pacific Northwest.* EPA 910/9-91-033. U.S. Environmental Protection Agency, Region 10, Seattle, WA.

USEPA. 1993. *Guidance specifying management* measures *for sources of nonpoint pollution in* coastal waters.. EPA 840-D-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Camp Creek Restoration, Crook County, Oregon

Camp Creek is located 40 mi (64 km) southeast of Prineville in Crook County, Oregon. It originates in the Maury Mountains of the Ochoco National Forest and drains to the east. The Camp Creek watershed drains approximately 110,710 acres (44,838 hectares) of rangeland consisting of sagebrush, juniper, and bunchgrass. This also includes coniferous forest habitat with elevations ranging between 3,665 and 6,12 1 ft (111 and 1865 m) . The drainage basin consists of fluvial valleys surrounded by more resistant basalt buttes and hills. Soils consist of highly erodible bentonitic and montmorillanitic clays. The climate is semiarid with 12 to 14 in (30.48 to 35.56 cm) of precipitation annually; 20 percent occurs as snow. Approximately 59,000 acres (23,895 hectares) of the watershed are public land, and the remainder is held by private landowners. Land use within the basin includes livestock and hay production.

Overgrazing, mismanagement of livestock, fire control, and intensive road/logging development since the late 1800s have accelerated stream bank and upland erosion, channel incision, dendritic gully spread, and riparian degradation, resulting in a drop in the local water table. As a result, sagebrush and juniper have since invaded the area, replacing native grasses and reducing available forage. In response to these disturbances, the BLM initiated the Camp Creek Restoration Project in 1965. Project objectives included (1) stabilizing the steam channel and the raising the water table on 31.6 river miles (50.844 km) and 383 acres (155 hectares) of riparian habitat, (2) improving stream water quality and reducing sediment discharge, (3) restoring the Camp Creek channel to 60 percent of its potential condition, and (4) increasing the forage resource base for wildlife and livestock.

In 1964, the BLM developed an initial Camp Creek watershed plan. Plan implementation included the following: (1) several detention dams were constructed, (2) 2.7 mi (4.34 km) of Camp Creek were fenced off, (3) 1,000 Russian olive seedlings and willow cuttings were planted along the upper portion of the creek, (4) severely disturbed areas were reseeded with tall wheatgrass and sweetclover, (5) stream banks were riprapped with juniper trees, (6) juniper and sagebrush were removed from several upland sites by cutting, chaining, and burning, and (7) low-rock structures and gabions were installed in the creek to trap sediment and raise the water table. In 1978 an intensive water quality and macroinvertebrate sampling survey was initiated. Following continued watershed surveys, a revised watershed plan was drafted in 1985, which initiated a new rest-rotation grazing plan. (Prior to this, grazing was year-round on open range.) Private landowners have also removed juniper and placed riprap along the creek on their property.

Monitoring of the Camp Creek restoration project included (1) establishment of permanent photo points on riparian and upland sites; (2) stream channel studies initiated in 1978 which included water quality and macroinvertebrate surveys; (3) permanent range condition transects; (4) upland erosion study plots; and (5) an intensive riparian zone hydrology study, which was initiated in 1985.

Success of the riparian restoration varied. Two to eight ft (0.51 to 2.44 m) of sediment was deposited behind instream structures. One livestock crossing effectively acted as a check dam. Beaver activity increased sediment deposition. Collectively these treatments have elevated the stream bottom and raised the water table within the floodplain. Juniper removal and prescribed burning enabled grasses to reestablish on upland sites, increasing available forage and augmenting infiltration of precipitation into the soil. Juniper riprapping stabilized stream banks and increased sediment deposition, allowing reestablishment of riparian plant species. Gabions were damaged by heavy flooding, however, a year after installation, and Russian olive and willow plantings were drowned out by the rising water table. Fenced enclosures have been only partially successful in limiting access of livestock to the creek. Several grazing permittees have failed to prevent their cattle from damaging fencing and grazing within the enclosures.

Juniper removal and reintroduction of fire into the ecosystem have been essential to the natural reestablishment of herbaceous plant species. Posttreatment structural maintenance has been necessary to achieve project objectives. A shift from year-round grazing to spring and late fall grazing adjacent to the riparian zone will protect fencing from damage incurred as cattle seek shade and water during the summer months. Greater supervision of the site by the BLM and grazing permittees will be necessary to keep cattle out of the riparian enclosures. Periodic surveys and monitoring have revealed unexpected changes in the riparian habitat, allowing the BLM to adopt new BMPs in response to these changes.

Financial support was appropriated from congressional funds, the Oregon Department of Fish and Wildlife, Oregon State University, range improvement funds returned from grazing permits, and local landowners.

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The Chewaucan River Project, Lake County, Oregon

The Chewaucan River is located in Lake County, Oregon, approximately 10 mi (16 km) southwest of Paisley, Oregon. The Chewaucan River Watershed drains approximately 30 m^2 (78 km^2) of grassland/forest habitat with an average elevation of 6,000 ft. The upper portion of the watershed is a grassland meadow where Dairy Creek and Elder Creek join to form Chewaucan River. Downstream, the river drains several steep-sided canyons separated by open meadows. Soils consist of alluvial material derived from adjacent highlands. The climate is semiarid with 20 in (50.8 cm) of precipitation annually; 50 percent occurs as snow. The river basin is used for cattle grazing, and several instream irrigation structures are present in the upper meadow (Schrader, 1991).

Overgrazing throughout the drainage basin degraded riparian habitat and reduced stream bank stability The confluence of Dairy Creek and Elder Creek was very unstable and highly eroded. Spring flooding accelerated bank erosion throughout much of the upper basin. In 1964, a flood event deposited flow out of the main stream channel, causing bank blowouts. A new landowner recognized these problems and enlisted the help of the Soil Conservation Service (now the Natural Resources Conservation Service) to obtain funding and expertise to rehabilitate the area. The two groups initiated the Chewaucan River Project. Project goals included (1) stabilizing stream banks, (2) enhancing riparian vegetation, (3) improving fish habitat, and (4) eliminating erosion caused by dead snags lodged in the lower portion of the river.

In 1988, approximately 2 mi (3.2 km) of riparian area in the upper meadow, including portions of Dairy Creek and Elder Creek, and 1 mi (1.6 km) in a downstream canyon were treated. Best management practices (BMPs) that were implemented included (1) riprapping stream banks with juniper; (2) riprapping the confluence of Dairy Creek and Elder Creek with stone material; (3) placing boulders in the river to enhance fish habitat; (4) removing snags from the lower portion of the river; (5) treating one highly disturbed stream corner with, a geotextile mat, which was then seeded and watered; (6) fencing 0.25 mi (0.4 km) of riparian pasture in the upper meadow; (7) planting willows throughout the basin, and 8) excluding the lower pasture from cattle grazing for 3 years.

Project monitoring was designed to include the establishment of five photo points along the river to be monitored annually for a period of 10 years. Willow growth is also to be monitored for 10 years.

Project results included increased sediment deposition in back eddies caused by juniper riprap, with riparian vegetation continuing to colonize the newly deposited sediment. Stream bank stability increased throughout the treated portions of the river. Stream banks that had sloughed onto riprapped sections were more sloped than previously. The geotextile mat worked very well to stabilize the adjacent stream bank; however, it probably will not be used again because of its expense. Removal of snags in the downstream reach oriented the river back into the main thalweg, reducing bank erosion. Willow plantings were not as successful as other treatments. Survivorship in the upper meadow was approximately 10 percent due to beaver cutting and 40 percent in the lower meadow (Schrader, 1991). No immediate benefits to the fishery from habitat enhancement have been recorded (Schrader, 1991).

The Chewaucan River Project cost in excess of $50,000, which was provided primarily by the Governor’s Watershed Enhancement Board with additional help from the Oregon Department of Fish and Wildlife, Soil Conservation Service, U.S. Forest Service, and owners of the J-Spear Ranch.

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Section 4 Best Management Practices

Introduction

This section describes some of the best management practices (BMPs) that might be useful in protecting natural wetlands from the effects of stormwater runoff or useful as part of a stormwater runoff treatment system that includes a natural wetland. The BMPs are grouped as follows:

- Nonstructural BMPs
  - Pollution Prevention
  - Watershed Management Plans
  - Preventive Construction Techniques
  - Outreach and Educational Programs
  - Riparian Areas
- Structural BMPs
  - Infiltration Basins
  - Infiltration Trenches
  - Sand Filters
  - Grassed Swales
  - Vegetative Filter Strips
  - Vegetated Natural Buffers
  - Open Spaces
  - Extended Detention Dry Basins
  - Wet Ponds
  - Constructed Wetlands
  - Porous Pavement and Concrete Grid Pavement
  - Oil/Grit Separators or Water Quality Inlets
  - Level Spreaders
  - French Drains
  - Dry Wells or Roof Downspout Systems
  - Exfiltration Trenches
- BMPs in Series

Each BMP is described in a fact sheet that includes specific information about the BMP The fact sheet for each nonstructural BMP includes a description of the practice and sources of additional information. The fact sheets for the structural BMPs, unconventional BMPs, and BMPs in series are more detailed and include a definition and purpose, the scope and applicability of the BMP, considerations for design criteria, potential impacts to wetlands, maintenance requirements, and sources of additional information, as applicable.

The fact sheets are intended to provide information about different BMPs for evaluation purposes. With information such as where a BMP is most applicable or what the potential impacts on wetlands might be, a planner or watershed manager can develop a stormwater management program that is as effective in protecting a wetland and all of its functions as it is effective in treating stormwater runoff.

It is important to note that the fact sheets are intended to be used as a planning tool and are not meant to be used in the design of any of the BMPs. Other sources of information, such as those listed at the end of each fact sheet, should be consulted for design, construction, and operation and maintenance of the BMPs. It should also be noted that the BMPs included in this document were selected because they have the potential, in a variety of situations, for reducing impacts from stormwater runoff to wetlands. There are other BMPs that are not addressed here, primarily because they might offer only one or two specialized applications to wetlands.

Remember to look at the site-specific conditions and develop a stormwater management program to protect an individual wetland based on those site-specific needs. Use the information provided in the first section of this document to help in identifying the particular conditions that are unique to the site and to choose one or more BMPs accordingly.

Nonstructural BMPs - Pollution Prevention

Definition/Purpose

Pollution prevention is defined as the reduction or elimination of pollutant discharges to the air, water, or land. Pollution prevention approaches to environmental protection include:

- Elimination of pollutants by substituting nonpolluting chemicals or products (e.g., material substitution, changes in product specification), or altering product use.
- Reducing the quantity and/or toxicity of pollutants generated by production processes through source reduction, waste minimization, and process modifications.
- Recycling of waste materials (e.g., reuse, reclamation).

Pollution prevention measures are used to reduce pollutant discharges and can be implemented to reduce nonpoint source pollutants generated from the following activities:

- The improper storage, use, and disposal of household hazardous chemicals, including automobile fluids, pesticides, paints, solvents, etc.
- Lawn and garden activities, including the application and disposal of lawn and garden care products and the improper disposal of leaves and yard trimmings.
- Turf management on golf courses, parks, and recreational areas.
- Improper operation and maintenance of onsite disposal systems.
- Discharge of pollutants into storm drains, including floatables, waste oil, and litter.
- Commercial activities such as parking lots, gas stations, etc.
- Improper disposal of pet excrement.
- Industrial wastewater disposal in septic systems.

Scope/Applicability

Pollution prevention practices can be applied to reduce the generation of nonpoint source pollution in all areas and for numerous activities (e.g., residential, commercial, industrial, institutional, transportation, public and private facilities). Pollution prevention is implemented through various educational, volunteer, and incentive programs and through federal, state, and local policies and regulations. Pollution prevention practices include the following:

- Promoting public education programs regarding proper use and disposal of household hazardous materials and chemicals.
- Establishing programs such as Amnesty Days to encourage proper disposal of household hazardous chemicals.
- Developing used oil, used antifreeze, and hazardous chemical recycling programs and site collection centers in convenient locations.
- Encouraging proper lawn management and landscaping that includes proper pesticide and herbicide use, reduced fertilizer applications and proper application timing, limiting lawn watering, xeriscaping, reduced runoff potential, and training, certification, and licensing programs for landscaping and lawn care professionals.
- Encouraging proper onsite recycling of yard trimmings.
- Encouraging the use of biodegradable cleaners and other alternatives to hazardous chemicals.
- Managing pet excrement to minimize runoff into surface waters,
- Using storm drain stenciling in appropriate areas.
- Encouraging alternative designs and maintenance strategies for impervious parking lots.
- Controlling commercial sources of NPS pollutants by promoting pollution prevention assessments and developing NPS pollution reduction strategies and training materials for the workplace.
- Promoting water conservation.
- Discouraging the use of septic system additives.
- Encouraging litter control.
- Promoting programs such as Adopt-a-Stream to assist in keeping waterways free of litter and other debris.
- Promoting proper operation and maintenance of onsite sewage disposal systems (OSDS) through public education and outreach programs.
- Encouraging closure of floor drains or shallow disposal wells that direct pollutants to groundwater.

Potential Impacts to Wetlands

Benefits

- Reduces pollutants at their source, thereby reducing pollutant loads in stormwater and downstream wetlands.

- Because discharges are prevented, reduces the need for structural BMPs and stormwater controls designed to remove pollutants from stormwater.

Limitations

- High participation crucial to success.
- Difficult to monitor results.

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Nonstructural BMPs - WatershedManagement Plans

Definition/Purpose

Watershed planning is a process for determining future activities within a watershed and should be a first step in implementing an effective stormwater/wetlands management program. Watershed planning usually involves the development of a watershed management plan that describes existing patterns of community life in a watershed-including demographic trends, housing, economic activity, natural resources, and infrastructure. In addition, watershed management plans should recommend goals and policies (including control of land use) to manage future development that should, in turn, minimize impacts on water resources, including wetlands.

A watershed management plan is based on a series of maps of the watershed and its resources. The watershed management plan also contains text that explicitly addresses conflicts and trade-offs among development, environmental protection, social issues (such as affordable housing), transportation, and many other factors. Special-purpose planning (including wellhead protection, underground injection control, and wetlands management planning) is one component of a watershed plan. A generalized watershed is shown in Figure 4-1.

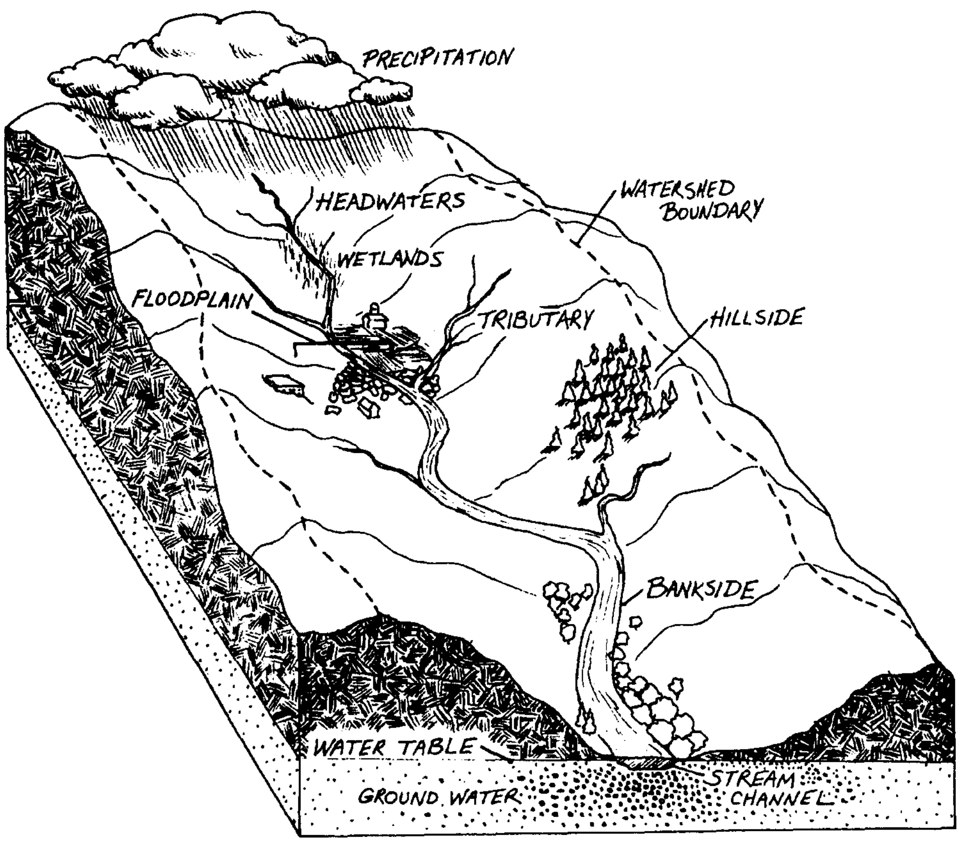


Figure 4-1. A generalized watershed showing natural and anthropogenic features.

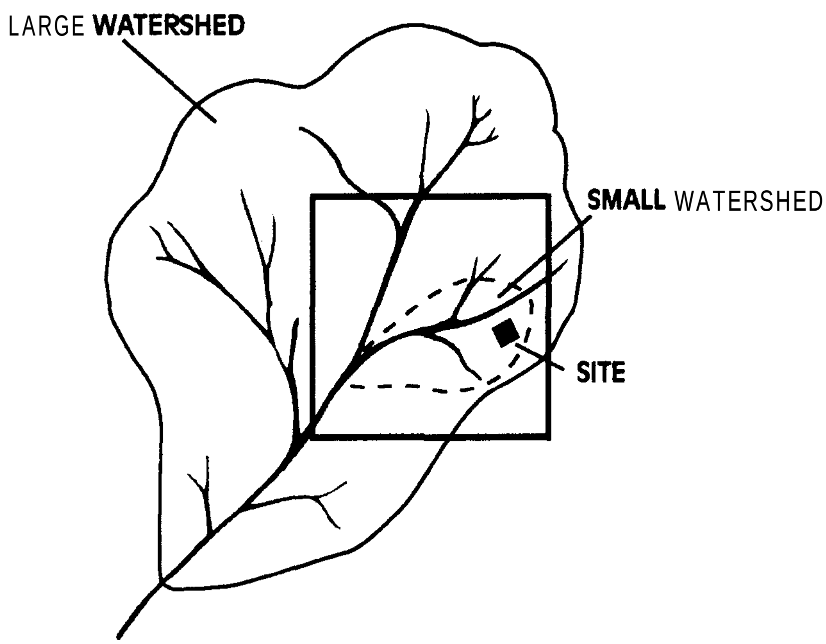
Scope/Applicability

Watershed management plans can be developed for any geographic area and are usually applied through the use of watershed overlay maps or a geographic information system. Most watershed management plans are implemented at the state and local government levels. Figures 4-2 and 4-3 indicate varieties of watershed management planning map resources.

Potential Impacts to Wetlands

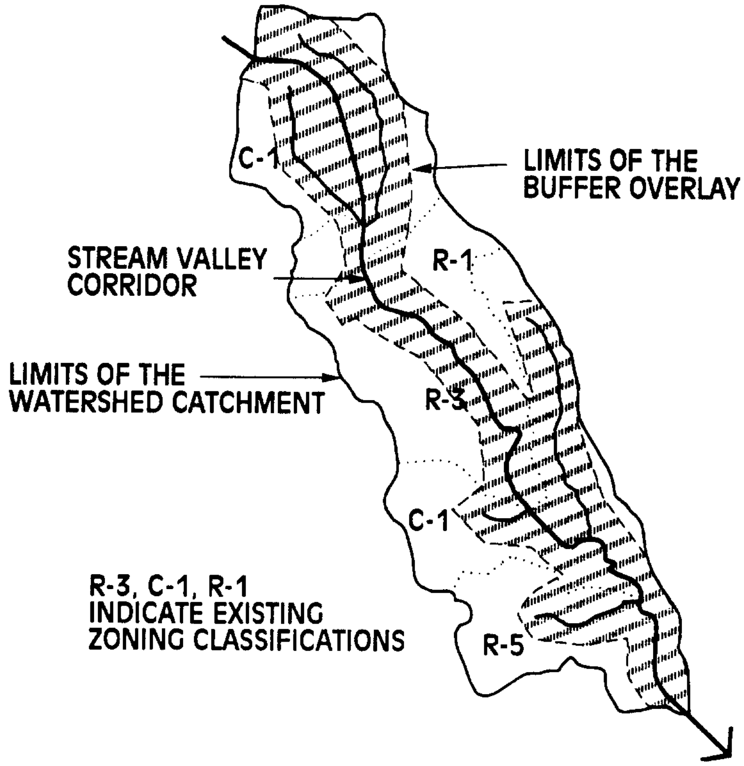
Benefits

- Allows for resource inventory, including identifying wetland resources on a watershed scale.
- Allows for information analysis, including locating individual wetlands with respect to other wetlands, adjacent land uses, and adjacent water bodies.
- Allows wetland managers to assess wetland protection needs, develop wetland protection and restoration goals, plan mitigation strategies, and determine impacts from land use changes to wetland resources.
- Serves as a modeling mechanism to be used for testing various land use/stormwater control scenarios within the watershed to determine options to best preserve overall wetland function or improve the health of a degraded wetland system.



Adapted from MWCOG, 1993.

Figure 4-2. Watersheds nest within each other. The site indicated lies within both a small watershed and larger watershed.



Adapted from MWCOG, 1993.

Figure 4-3. Overlay zoning adds another measure ofprotection to critical resources.

Limitations

- Watershed boundaries frequently overlap political boundaries.

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Nonstructural BMPs - preventive Construction Techniques

Definition/Purpose

Preventive construction techniques are practices applied to construction sites to control pollution at the source. Pollution source controls are implemented throughgood management and housekeeping techniques designed to minimize nonpoint source pollution from the sites. Typically, preventive construction techniques are developed to control runoff volumes and sediment, but they can also be designed to control other NPS pollutants such as nutrients, oil and grease, and pesticides.

An overall management plan for the control of nonpoint source pollution on a construction site that addresses specific control measures to be implemented in an effective manner can be applied as a preventive construction technique. The construction site pollution control plan should address specific categories including erosion and sediment controls, equipment maintenance and repairs, waste collection and disposal, storm sewer inlet protection, dust controls, storage of construction materials, washing areas, demolition areas, sanitary facilities, and pest controls. Some management and housekeeping techniques applied to these categories should include the development and implementation of an effective erosion and sediment control plan; the proper location of activities that can act as a source of pollutants to wetlands, streams, or stormwater conveyance systems in areas that are not subject to surface water runoff; the placement of filtering devices to protect conveyance systems from settleable pollutants during construction; the proper use and storage of chemicals; proper collection and disposal of wastes on a site with adequate and properly located receptacles; and the maintenance of a site in a neat and orderly condition.

Preventive construction techniques are used to minimize the contamination of stormwater on a site by reducing the availability of construction-related pollutants that might contaminate runoff. Where the contamination of runoff water cannot be avoided, pollutants and polluted water are controlled on site.

Scope/Applicability

Preventive construction techniques can be applied to all construction projects. The planning and management techniques applied to a location should be adapted to the site- specific characteristics of a project. The degree of planning and management necessary to prevent or minimize nonpoint source pollution on a site will depend, primarily, on the size and complexity of the project. See Figure 4-4.

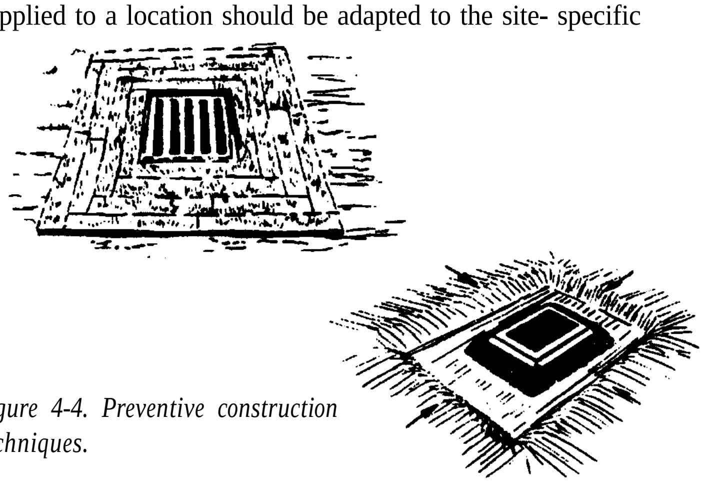

Figure 4-4. Preventive construction techniques.

Design Criteria Considerations

- Develop an overall plan for the control of nonpoint source pollution that addresses specific measures that can be described and implemented in an effective manner.
- Develop a plan that is specific to the characteristics of a site.

Potential Impacts to wetlands

Benefits

- Reduction in the amount of stormwater-associated pollutants entering adjacent or downstream wetlands.
- Reduction of construction site erosion resulting in a reduction of stormwater sediment loads to downstream wetlands.
- Reduction in the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.

Limitations

- Possible reduction in the amount of surface water supplied to adjacent or downstream wetlands as a result of rerouting.

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Nonstructural BMPs - Outreach and Education Programs

Definition/Purpose

Educational programs should improve wetlands protection program implementation by maintenance personnel and government officials and should reduce individual contributions to stormwater problems. Training programs and educational materials for public officials, contractors, and the public are crucial to implementing effective stormwater management programs. Educational programs for public officials, contractors, and the public are also necessary to teach the value of natural wetlands and the potential impacts of stormwater runoff. Contractor certification and inspector training are important educational programs that add to the success of stormwater management programs and their continued effectiveness. Programs for the public can educate and encourage participation and support for pollution prevention efforts such as storm drain stenciling, used oil and hazardous chemical recycling, litter control, street sweeping, lawn management and landscaping, safe use and disposal of household hazardous materials and chemicals, correct operation of onsite disposal systems, proper pet excrement disposal, water conservation, and closure of shallow disposal systems that direct pollutants to groundwater.

Scope/Appilcability

Educational programs can be implemented in homes, residential communities, and at the workplace. Training and certification programs can be implemented at all levels of government and through numerous private and public institutions involved in wetland and stormwater management including developers, contractors, scientists, engineers, and professional associations. The states of New Jersey, Virginia, Maryland, Washington, and Delaware, and the city of Alexandria, Virginia, are examples of governments whose agencies have developed manuals and training materials to assist in the implementation of urban runoff requirements and regulations (USEPA, 1993).

Numerous public and private institutions are involved in or sponsor public education programs, such as environmental organizations; neighborhood, business, civic, and professional associations; school systems; churches; Boy Scouts and Girl Scouts of America; and 4-H Clubs. A common program is storm drain stenciling to enhance public awareness (see Figure 4-5). Educational programs can be achieved through various public outreach media, including newsletters, magazines, newspaper, audiovisuals, public meetings, or workshops.

Figure 4-5. Stencil spray painting to enhance public awareness.

Potential Impacts to Wetlands

Benefits

- Teaches the public the value of natural wetlands and the positive and negative impacts of stormwater.
- Teaches the public how pollutants can impact wetlands via stormwater runoff and how to prevent pollution from entering surface waters and groundwaters.
- Provides opportunities for the public to participate in decision-making activities, to observe wetlands and other aquatic ecosystems, and to gain "hands on" experience in the field.
- Prepares government officials and personnel to implement their stormwater and wetland programs effectively and consistently, to make educated decisions regarding stormwater controls, and to communicate the goals and objectives of stormwater/wetland policies to the public.

Limitations

- High participation crucial to the success of many public education programs
- Difficult to monitor results.
- Program results might not be realized for some time.
- Programs require continuous funding and demands on personal time.

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Nonstructural BMPs - Riparian Areas

Definition/Purpose

Riparian areas are vegetated ecosystems along a water body through which energy, material, and water pass. These areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent water body. Riparian areas encompass wetlands, uplands, or combinations of these areas, and environmental conditions in the zone at times resemble both wetland and upland. The complex organizations of biotic and abiotic elements that make up riparian areas can be effective in removing suspended solids, nutrients, and other contaminants from stormwater runoff.

Maintaining natural riparian areas helps to slow stormwater runoff, trap sediment, and reduce the volume of runoff by allowing some infiltration to occur. Reducing the velocity of stormwater runoff attenuates soil erosion processes and increases runoff contact time with soil and vegetative surfaces. Increased contact of stormwater runoff with the soils and vegetation in a riparian area can result in the infiltration of runoff and the filtration or uptake of stormwater-associated pollutants.

Riparian areas are important to both the wetland and the upland as habitat for aquatic and wetland-dependent wildlife species, as refuges for wildlife species during high-water events, as seed reservoirs, and as buffers against extreme environmental conditions. Other functions of riparian areas that contribute to water quality include shading, flood attenuation, and shoreline stabilization. A typical riparian area is shown in Figure 4-6.

Scope/Applicability

Where natural riparian areas are present, they should be maintained around all wetlands that might be impacted by stormwater flows. The removal of trees and other vegetation in the riparian zone should be limited and heavy use should be minimized to reduce the potential for soil compaction, which could result in decreased infiltration rates.

Figure 4-6. A typical riparian area.

Riparian areas should be a part of a series of BMPs for treating stormwater in densely developed areas where there are high percentages of impervious surfaces or where discharge rates are high and flow is concentrated.

Riparian areas should be maintained, when possible, in all areas where they exist and can be combined with other structural or nonstructural BMPs as part of a stormwater treatment system. They are useful in separating incompatible land uses, and can be effective in protecting sensitive habitats such as wetlands, streams, lakes, and shorelines from adjacent land uses.

Design Criteria Considerations

- Maintain natural vegetation.
- Avoid compaction of the soils.
- Consider slope, vegetation, soils, depth to impermeable layers, runoff sediment characteristics, type and quantity of stormwater pollutants, and annual rainfall when determining widths.
- Increase riparian area width with increased slope, where possible.
- Combine natural riparian areas with other structural or nonstructural BMPs as pretreatment where discharge rates are high or flows are concentrated.

Potential Impacts to Wetlands

Benefits

- Reduce the amount of stormwater-associated pollutants entering adjacent or downstream wetlands.
- Reduce stormwater sediment loads to downstream wetlands.
- Reduce the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.

- Might result in recharge of groundwater from infiltration, benefiting adjacent baseflow-dependent wetlands.
- Maintain slope stability adjacent to wetlands and streams.
- Provide a buffer between wetlands and adjacent land uses.
- Provide critical habitat adjacent to wetlands and streams.
- Protect aquatic life by preventing and reducing thermal warming impacts.

Limitations

- Might not adequately attenuate concentrated peak stormwater flows to adjacent or downstream wetlands.

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Structural BMPs - Information Basins

Definition/Purpose

Infiltration basins are stormwater impoundments that detain stormwater runoff and return it to the ground by allowing runoff to infiltrate gradually through the soils of the bed and sides of the basin. Infiltration basins are flat-bottomed, have no outlet, and are usually located to collect stormwater runoff from adjacent drainage areas. Infiltration basins can be designed to control peak discharges from relatively large design storms.

Infiltration basins can be designed as an off-line system for treating the first flush of stormwater flows or to treat the peak discharges of the 2-year storm event. They remove both soluble and fine particulate pollutants, provide groundwater recharge, and preserve the natural water balance of a site by diverting a signifcant fraction of the annual runoff volume back into the soil. Infiltration basins can maintain flow levels in small headwater streams during critical dry-weather periods. They do not produce thermal or low dissolved oxygen impacts to downstream waters as do wet ponds. Infiltration basins can be used as sediment basins during the construction phase of a site as long as the sediment is removed prior to final grading of the basin.

Scope/Applicability

Infiltration basins are effective at removing both soluble and fine particulates found in stormwater runoff. (Coarse-grained pollutants should generally be removed before they enter an infiltration basin.) Unlike other infiltration devices (e.g., trenches), basins can be adapted to provide full control of peak discharges for large design storms. Infiltration basins can also be adapted to relatively large drainage areas (up to 50 acres). Depending on the degree of storage/exfiltration achieved in the basin, significant groundwater recharge, low flow augmentation, and localized stream bank erosion control can be achieved (Schueler, 1987).

Infiltration basins can be used at locations with sufficient open space and proper topography to allow gravity flow of stormwater to the basin. They are usually used in commercial and large residential developments. Infiltration basins can serve drainage areas of 2 to 50 acres, depending on local conditions. An infiltration basin must be located in permeable soils with infiltration rates greater than 0.5 inches per hour. Soil and water table conditions should be such that the system can provide for a new volume of storage through percolation or evapotranspiration within a maximum of 72 hours following a stormwater event.

The use of infiltration basins is not recommended in the following situations: ultra-urban areas, watersheds with risk of chronic oil spills or other contaminant spills, regions with cold winters and snowmelt/freeze and thaw conditions, arid regions where a dense vegetative cover cannot be reliably maintained, regions with sole-source aquifers, and areas with predominantly clay or silt soils. Soils with a combined silt/clay percentage of over 40 percent by weight are susceptible to frost heave and are not good candidates for infiltration basin applications. Basins are also unsuitable if the site is located over fill soils that form an unstable upgrade and are prone to slope failure.

It should be noted that infiltration basins have a high failure rate due to the tendency of the basin soils to become clogged with sediments. Failure rates for infiltration basins in the mid-Atlantic region range form 60 to 100 percent in the first 5 years, according to studies conducted in Maryland (Schueler, 1992). Once a basin has become clogged, it is very difficult to restore its original function; thus, many infiltration basins have been converted to retention basins or constructed wetlands.

Design Criteria Consideration

- Detention of the 2-year, 6-hour minimum storm to 72-hour maximum drawdown time.
- Recommended size of contributing drainage area based on site-specific conditions (e.g., soil infiltration capacity or rainfall).
- Pretreatment sediment forebay to dissipate the velocity of incoming runoff, spread the flow, and trap the sediment.

- Offsets to waterwells, onsite disposal systems, and fundations are based on hydrologic, soil, ecologic, and topographic characteristics of the site or existing state or local requirements.
- Flat-bottomed basin floor vegetated with dense turf grass, such as reed canary grass or tall fescue.
- Shallow/Basin depth with inlet level with basin floor.
- Riprap apron at inlet to prevent incoming runoff from reaching erosive energy levels and scouring the pipe outfalls and to spread incoming runoff more evenly.
- Emergency spillway.
- Maximum side slopes of 3:l (h:v) to allow vegetative stabilization, easier mowing, and public safety
- Riprap level spreaders.
- Uniform ponding depth across entire surface of basin; low spots should be leveled.
- Contributing watershed slope less than 20 percent; 5 percent optimal.
- Minimum 4-ft clearance between basin floor and bedrock level.
- Minimum 4-ft clearance to seasonally high groundwater table.
- Minimum 100 ft from drinking water wells.
- Minimum 10 ft downgradient and 100 ft upgradient of foundations.
- 25ft vegetated buffer around the basin perimeter; low-maintenance, water-tolerant native plant species that provide food and cover for wildlife and act as a screen.
- Initial and periodic tilling of basin floor.
- Use of lightweight equipment in basin.
- Maximum depth low enough to ensure complete drainage of basin within 72 hours; depends on soil types present.

Design Considerations to Improve Longevity

- Stone trenches.
- Sand surface layer.
- Underdrains below basin floor.
- Shorter dewatering rate (24 hr rather than 72 hr).
- Pretreatment forebays to control sediment inputs.
- Small contributing watershed areas.
- Shallow basin depths (standing water appears to promote soil compaction).
- Off-line designs that bypass large storms and sediment inputs.
- More efficient dewatering mechanisms in basins (e.g., stone trenches rather than soil).
- Careful geotechnical investigation of soil conditions prior to excavation.

Potential Impacts to Wetlands

Benefits

- Recharge of groundwater from infiltration basins, benefiting baseflow-dependent wetlands.
- Reduction of stormwater sediment loads to downstream wetlands.
- Reduction in the potential for downstream wetland degradation resulting from erosion and hydroperiod changes associated with stormwater flows.
- Reduction in the amount of stormwater-associated pollutants entering downstream wetlands.

Limitations

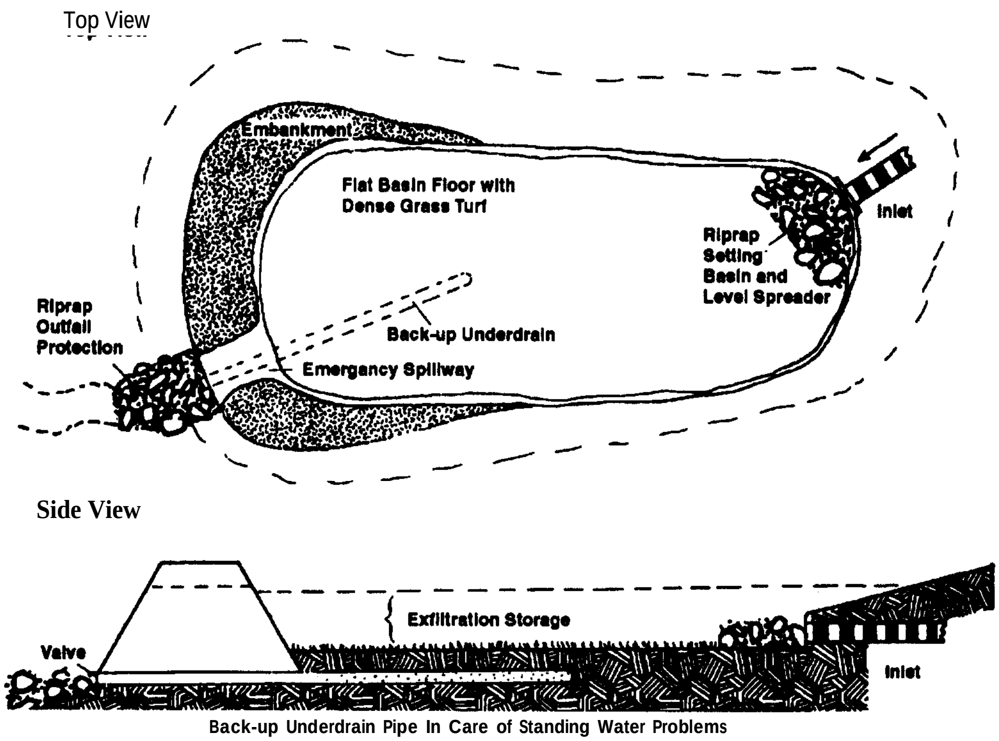
- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as the result of rerouting and detention.
- Short life span (5 years or less).
- Might not be applicable in cold or arid climates, areas with impermeable soils, or areas overlying sole source aquifers.
- Filtering effect of the topsoil can be lost by distributing runoff directly into the subsoil horizon.

Maintenance Requirements

Infiltration basins require relatively frequent inspection and maintenance. Infiltration basins require inspection, sediment removal, tilling, erosion control, and debris and litter removal. The frequency of sediment removal will depend on whether the basin is vegetated or nonvegetated, its storage capacity, its recharge characteristics, the volume of inflow, and the sediment load.

Infiltration basins require more frequent inspections after construction (see Figure 4-7), with inspections tapering off to twice a year once performance has been verified. Once the basin is put to use, it should be inspected after every major storm or at least once a month if no major storm occurs. Inspections include monitoring of water levels for drainage and checking for accumulation of sediment or signs of erosion or contamination.

Sediment removal from infiltration basins without vegetation should be performed annually or semiannually followed by tilling to maintain infiltration rates. Sediment removal should be performed when the basin is dry to prevent compaction of the soils and clogging of infiltrative surfaces. Care should be taken to avoid compaction of the basin floor by using light equipment or possibly hand raking to remove sediments. After the sediment is removed, the basin should be tilled. Rotary tillers or disk harrows are normally used, but deep plowing might be necessary if heavy equipment has compacted the soil. Removal of sediments from vegetated basins might not need to be performed as frequently because vegetative growth helps to prevent the formation of impermeable layers on the surface of the soil. Dense vegetative growth on side slopes and buffer strips will also help to prevent erosion from occurring.



Schueler. 1997.

Figure 4-7. Two views of an infiltration basin.

The basin should be checked annually for structural stability including the erosion of side slopes, differential settlement, cracking, leakage, or tree growth on the embankments. Erosion control is very important because the associated sediments can clog the infiltration basin. The erosion of side slopes can be prevented by the maintenance of a dense turf having extensive root growth that promotes infiltration through the basin sides, promotes bed stability, and inhibits weed growth.

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Structural BMPs - Infiltration Trenches

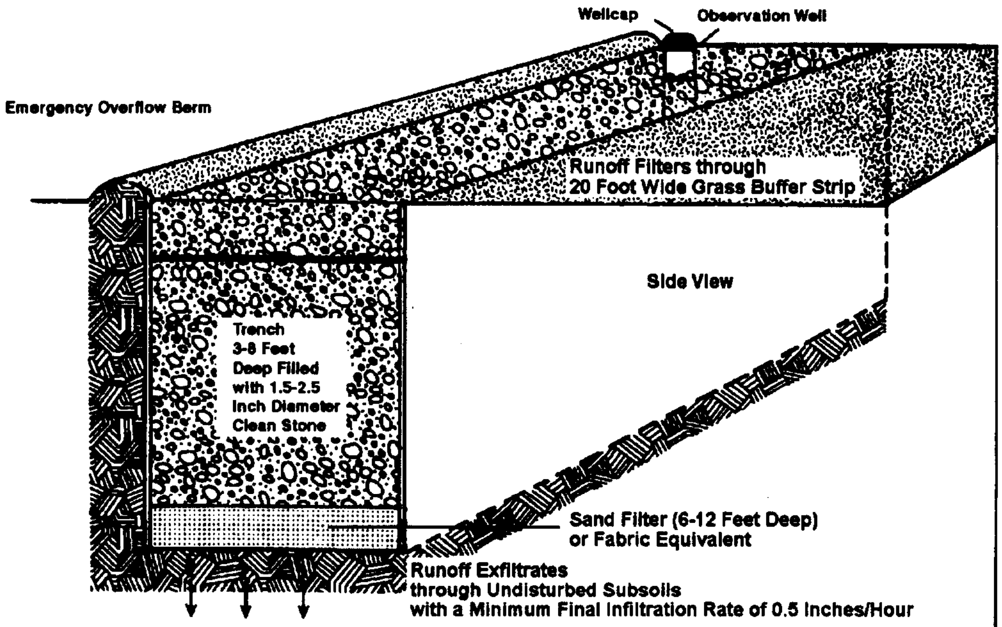
Definition/Purpose

An infiltration trench is an excavated trench backfilled with clean, coarse aggregate to allow for the temporary storage of runoff. Runoff stored in the trench is allowed to infiltrate into the soil in the trench bottom or is conveyed from the trench by an outflow pipe to downstream stormwater detention or retention systems. Infiltration trenches are designed to provide temporary storage and infiltration for increased stormwater runoff associated with development. Infiltration trenches can attenuate peak discharges associated with the design storm and may replicate predevelopment hydrologic conditions.

Infiltration trenches remove fine particulates and soluble pollutants from runoff by temporary storage and infiltration into the underlying soil. Pollutant removal from runoff in infiltration trenches results from adsorption, filtration, and microbial decomposition in the soil. Temporary storage and partial or complete infiltration of runoff in an infiltration basin can also reduce downstream bankfull flooding and resultant stream bank erosion and can help to maintain baseflow conditions. A typical infiltration trench is shown in Figure, 4-8.

Scope/Applicability

Infiltration trenches can be used on small individual sites or can be incorporated into multiuse sites where open area is restricted. Pretreatment devices such as grassed swales or filter



Schueler, 1987.

Figure 4-8. Typical infiltration trench.

strips should be incorporated with infiltration trenches to remove coarse particulates from runoff prior to its entering the trench.

Infiltration trenches should not be located in areas with shallow groundwater or adjacent to groundwater-maintained wetlands because of the potential for adverse impacts resulting from pollutants in the stormwater. Potential impacts to the natural hydroperiod of existing surface water-maintained wetlands resulting from the rerouting of water through infiltration trenches and away from these systems should also be considered.

Contributing areas should be less than 10 acres in size, and slopes should be less than 5 percent. Infiltration trenches cannot be installed in fill and should not be used in areas with low-permeability soils. Their use may also be limited in areas where the ground remains frozen at depth for extended periods of time or in arid areas with sparse vegetative cover.

Design Criteria Considerations

- Location in suitable soils with sufficient infiltration rates, preferably greater than 0.5 inches per hour.
- Water table offset of at least 3 ft from the bottom of the trench.
- Contributing area of less than 10 acres.
- Contributing slopes of less than 5 percent.
- Detention time of 48 to 72 hours to allow adequate pollutant removal.
- Complete drainage of trench within 72 hours of a storm event to maintain aerobic conditions
- Pretreatment of stormwater inflow to remove coarse sediments.

- Sizing of trench dependent on the volume of runoff to be controlled.
- Use of observation wells to monitor performance.
- Level trench bottom.
- Offsets to waterwells, onsite disposal systems, foundations, etc. based on hydrologic, soil, ecologic, and topographic characteristics of the site or existing state or local requirements.

Design Considerations to Improve Longevity

- Field verification of soil infiltration rates and water table location.
- Use of pretreatment systems that provide some degree of storage (e.g., sump pits, swales with check dams, plunge pools).
- A layer of filter fabric 1 ft below surface of trench.
- Use of a sand layer rather than filter fabric at the bottom of the trench.
- Avoiding construction until all contributing watershed disturbances and construction activities are completed.
- Rototilling of trench bottom to preserve infiltration rates.

Potential Impacts to Wetlands

Benefits

- Reduction of stormwater sediment loads to downstream wetlands.
- Reduction in the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.
- Reduction in the amount of stormwater-associated pollutants entering downstream wetlands.

Limitations

- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as the result of rerouting.
- Embedding of downstream wetland substrates as the result of the removal of coarse sediments.
- Might not be applicable in cold or arid climates, areas with impermeable soils, or areas overlying sole source aquifers.
- Filtering effect of the topsoil can be lost by distributing runoff directly into the subsoil horizon.

Maintenance Requirements

Infiltration trenches require periodic low-level maintenance. Because trenches are typically smaller than other BMPs and are buried underground, they might receive little attention from homeowners or might be relatively inaccessible. Infiltration trenches require continued monitoring and maintenance according to a well-defined schedule that outlines responsibilities and enforcement. Routine maintenance activities include inspection, buffer maintenance and mowing, sediment removal, and tree pruning.

Inspections for drainage are typically performed frequently upon completion of construction and annually thereafter. Water level monitoring should be conducted several times within the first few months of operation. The surface of the infiltration trench should be checked for standing water after a rainstorm, and water levels in the observation well should be recorded over several days to check drainage rates. If there is no observation well, a small hole can be dug down to the first layer of filter fabric to observe the water level in the trench. The monitoring schedule is reduced to an annual frequency once performance of the device has been verified.

The accumulation of sediments in the top foot of stone aggregate or the surface inlet should be monitored on the same schedule as the observation well to check for surface clogging. When infiltrative capacity is significantly reduced, sediment should be removed from the top of the infiltration trench by removing the stone, replacing the filter fabric, and washing or replacing the stone. Removal of sediment from the top of the infiltration trench should be required less frequently if the trench is designed with a pretreatment inlet. Sediment should be cleaned out of the pretreatment inlet, sediment trap, or grease trap on a regular basis.

Grass buffer strips adjacent to and growing over the infiltration trench should be inspected annually for lush, vigorous growth. Bare spots should be reseeded or resodded, and eroded areas should be repaired. Trees adjacent to the trench should be trimmed so that their leaves will not clog the trench. Pioneer trees that start to grow near the trench should be removed to prevent puncturing of the trench by their roots,

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Structural BMPs - Sand Filters

Definition/Purpose

Sand filters are systems of underground pipes beneath a self-contained bed of sand designed to treat urban stormwater. Runoff from a developed site is routed to the filters, infiltrated through the sand, then collected in underground pipes and returned back to the stream or channel. Sand filters are enhanced with the use of peat, limestone, gravel, and/or topsoil layers and may have a grass cover. Sand filters remove sediment, trace metals, nutrients, BOD, and fecal coliform from the initial pulse of stormwater from a development site. They provide significant pollutant removal and are useful for groundwater protection.

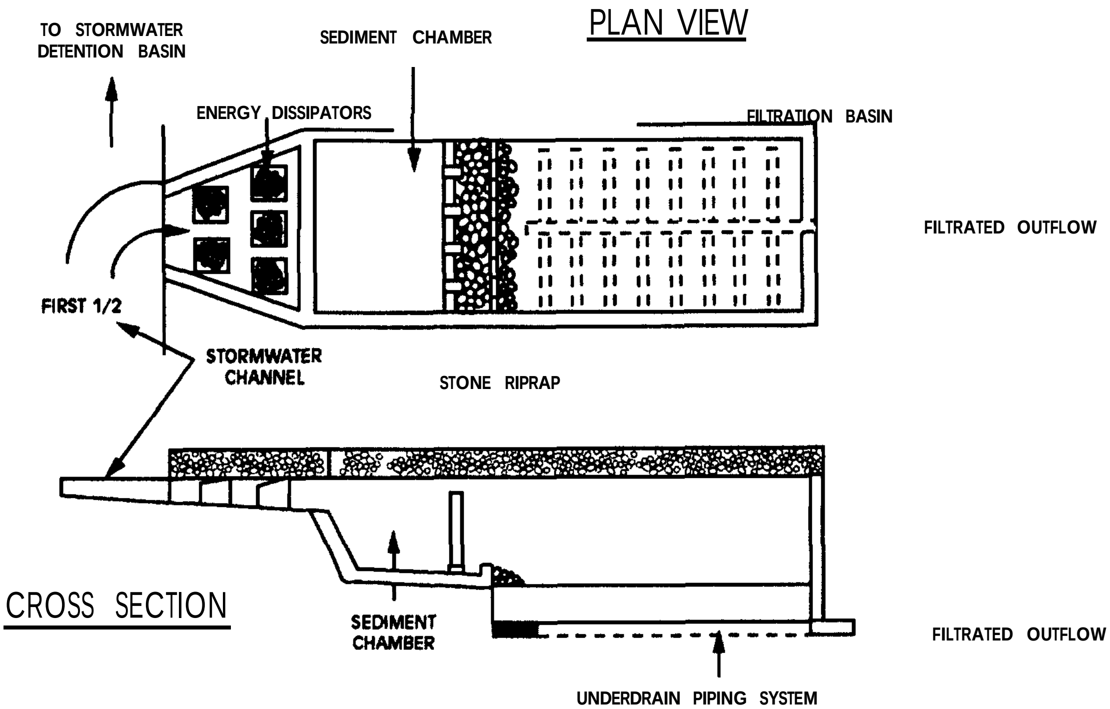
Scope/Applicability

Sand filters are adaptable for urban areas. They can be used to treat stormwater from small, intensely developed sites (e.g., gas stations, convenience stores, small parking lots). Sand filters have been used to retrofit existing stormwater management systems by locating them at the end of existing stormwater outlet pipes. Sand filters are an off-line system (i.e., they should be located outside the stream channel or drainage path). Sand filters are more costly to construct than infiltration trenches by a factor of 2 or 3, but they have lower regular maintenance costs.

Sand filters are designed to treat stormwater quality, not quantity They have a limited ability to reduce peak discharges and do not provide detention for downstream areas such as wetlands. Average removal rates of 85 percent for sediment, 35 percent for nitrogen, 40 percent for dissolved phosphorus, 40 percent for fecal coliform, and 50 to 70 percent for metals have been reported for sand filters. Two views of a sand filter design developed by the City of Austin, Texas, are presented in Figure 4-9.

Design Criteria Considerations

- Sand filters can be used in areas with thin soils, high evaporation rates, low soil infiltration rates, and limited space.
- Drainage areas can be as great as 50 acres; however, most sand filters will function well with contributing watersheds ranging from 0.5 to 10 acres.
- Two to 4 ft of head are needed for proper operation.
- Using a peat or limestone layer in the filter bed and a grass cover can increase the pollutant removal efficiency
- Minimum design depth of the filter should be 18 inches.
- Filters designed with a long drawdown time (24 to 40 hours) can increase the pollutant removal efficiency



City of Austin, Texas, 1991.

Figure 4-9. Two views of a sand filter design.

Design Considerations to Improve Longevity

- Quarterly maintenance of the sand filter to maintain porosity aids in keeping the filter operating efficiently
- Designs that include a flow splitter can help to prevent clogging.
- Pretreatment to remove sediment will help to prevent clogging.
- Designs that allow for access to the filter aid in maintenance and inspection of the filter.
- Regular removal of surface sediment increases the longevity of the filter.

Potential Impacts to Wetlands

Benefits

- Reduction in the amount of stormwater-associated pollutants entering downstream wetlands.

Limitations

- Primarily function as a water quality BMP and might not adequately attenuate concentrated peak stormwater flows to adjacent or downstream wetlands.
- Might adversely affect downstream sediment or nutrient-depleted wetlands.

Maintenance Requirements

Sand filters require relatively frequent yet simple inspection and maintenance to maintain performance. When a predetermined headloss is reached, the top layer of sand is removed and replaced to restore the filtration capacity of the filter. The frequency of sediment removal depends on the solids content of the water being filtered. To extend the life of the filter, system designs incorporate a wet pool that is used to trap the coarse sediments before they reach the filter. Sand filters require raking, surface sediment removal, and the removal of trash, debris, and leaf litter. Peat-sand filters that have vegetation growing on their surface require vegetation maintenance including periodic mowing. Mowing the grass short removes nutrients absorbed by the plants and maintains a neat filter appearance.

Sand filters require monitoring for hydraulic conductivity. Routine inspections are also needed for sediment accumulation in the wet pool, health of the vegetative cover, and the removal of trash deposited in the wet pond. The vegetative cover can be damaged by salt if the system is not shut down over the winter season. Managers should select hardy vegetation that is resistant to damage by salt, disease, and flooding.

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Structural BMPs - Grassed Swales

Definition/Purpose

Grassed swales are channels lined with grass or erosion-resistant plant species that are constructed for the stable conveyance of stormwater runoff. They use the ability of vegetation to reduce the flow velocities associated with concentrated runoff. Grassed swales are not usually designed to control peak runoff loads independently and are often used in combination with other best management practices. Where slopes are excessive, grassed swales can include excavated depressions or check dams to enhance runoff storage or to decrease flow rates.

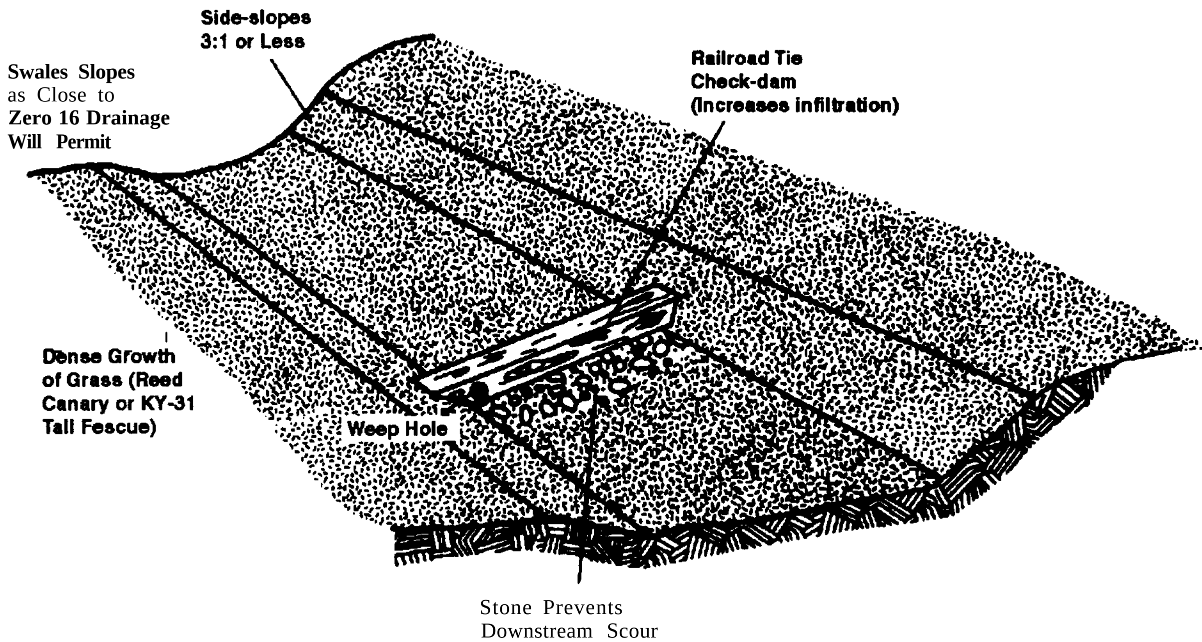
Grassed swales are primarily stormwater conveyance systems designed to channel and transport stormwater without the resultant erosion associated with high-velocity runoff. The reduction in flow velocities resulting from the conveyance of surface runoff through dense vegetative cover can result in a reduction of peak discharges. Pollutants can be removed from stormwater by filtration through the vegetation, by deposition, or in some cases by the infiltration of soluble nutrients into the soil. The degree of pollutant removal in a swale depends primarily on the residence time of water in the swale and the extent of its contact with vegetation and the soil surface. The incorporation of excavated depressions or check dams into grassed swales can enhance pollutant removal by increasing detention/retention times. An example of a grassed swale is shown in Figure 4-10.

Scope/Applicability

Grassed swales can be used in large-lot single-family subdivisions and on campus-type office or industrial sites in place of curbs and gutters. They are useful for runoff conveyance in highway medians and are often combined with other best management practices. They can be used in all areas of the country where the climate and soils allow for the establishment of dense vegetative covers. Grassed swales have a limited ability to control runoff from large storms and shouldnot be used in areas where flow rates exceed 1.5 ft per second.

Design Criteria Considerations

- Longitudinal swale slope of less than 2 percent or use of check dams or excavated depressions where slopes exceed 4 percent.
- Wide and shallow parabolic shape with side slopes of less than 3:1.
- Development and maintenance of dense vegetation.
- Greater than a 2-ft offset to the water table.



Schueler. 1987.

Figure 4-40. Grassed swale.

- Use of underdrains if well-drained conditions are required.
- Discharge of runoff to wetlands or adjacent BMPs at nonerosive velocities.

Potential Impacts to Wetlands

Benefits

- Potential creation of wetlands and wetland habitat in low-slope areas.
- Potential for groundwater recharge in low-flow storm events, benefiting adjacent baseflow-dependent wetlands.

Limitations

- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as a result of the rerouting of surface water.
- Potential for the introduction of pollutants to downstream wetlands during peak storm events if conveyance is to the wetlands.

Maintanance Requirements

Maintenance requirements for grassed swales are relatively minimal. These include cleanout of sediment trapped behind check dams, mowing, litter removal, and spot vegetation repair. The most important objective in the maintenance of grassed swales is the maintaining of a dense and vigorous growth of turf. Usually in residential subdivisions, homeowners adjacent to the swales maintain the grass and remove litter. Education of homeowners is recommended because the type of maintenance sought to maximize pollutant removal is somewhat different from that used to maintain the average homeowner's lawn. For example, grass should not be cut too short, excessive fertilizers should not be used so that contamination of receiving waters or groundwater is avoided, and ditches should be kept free of lawn debris.

Periodic cleaning of vegetation and soil buildup in curb cuts is required so that water flow into the swale is unobstructed. Sediments should be removed when they accumulate to 6 inches or more at any spot or when they interfere with the grassed swale operation. During the growing season, swale grass should be cut no shorter than the level of the design flow. Cuttings should be removed promptly. Swale maintenance at the end of the growing season depends on whether the objective is to remove nutrients or particulates. Grasses and wetland plants are mowed or cut to a low height at the end of the growing season to promote nutrient removal; for other pollution control objectives, such as sediment removal, plants are allowed to stand at a height exceeding the design water depth by at least 2 inches at the end of the growing season. These plants will act as a filter to screen out particles by slowing the velocity of water so that particles can settle.

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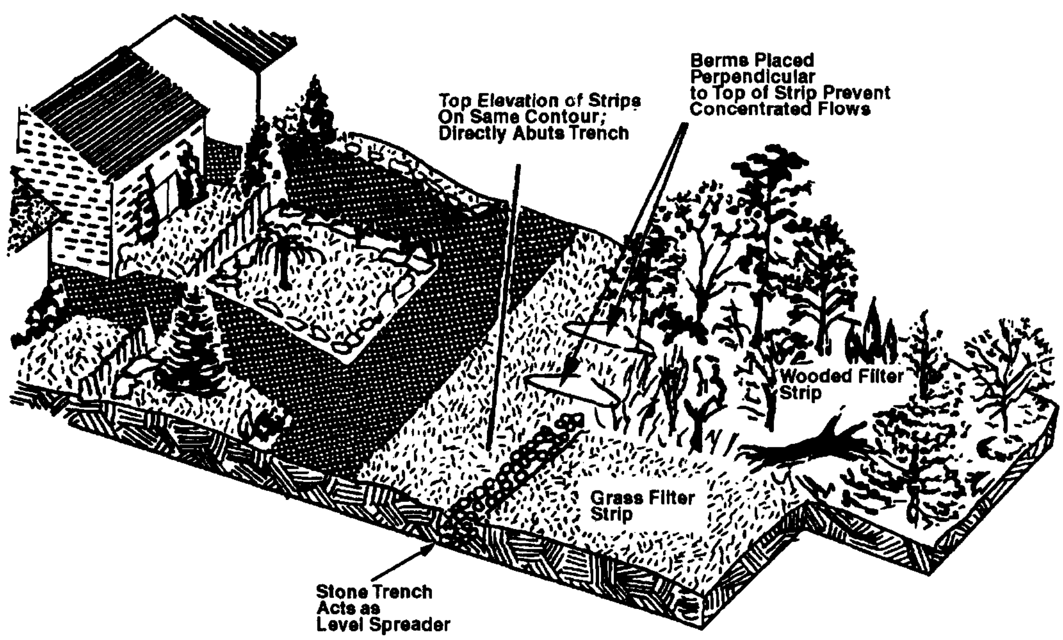
Structural BMPs - Vegetative Filter Strips

Definition/Purpose

Vegetative filter strips are densely vegetated sections of land designed to convey runoff in the form of sheet flow from adjacent developed sites. Level spreaders can be incorporated into the design of vegetated filter strips to increase their effectiveness by distributing runoff over the full length of the strip. Vegetative filter strips primarily function as water quality BMPs and do not provide adequate detention or infiltration to reduce peak discharges to predevelopment levels.

Vegetative filter strips direct runoff in the form of sheet flow across grassed or forested surfaces (see Figure 4-11). Reduction in flow velocities resulting from the conveyance of surface runoff through dense vegetated cover results in the removal of particulate contaminants through sedimentation, enhanced infiltration into the soil, and a reduction in the potential for down-stream channel degradation. Vegetative filter strips may also reduce runoff volumes and contribute to groundwater recharge. Maximum water quality benefits of vegetative filter strips can be obtained if the strips include the use of native vegetation (preferably undisturbed or conserved natural areas).

A recent variation of vegetative filter strips is a technology referred to as bioretention. This approach can be suitable for managing runoff from small drainage areas using a mixture of upland plant materials and enriched soil composition. Bioretention can maximize nutrient uptake, evapo-transpiration, infiltration, microbial degradation of metals and carbon-based pollutants, and storage to help reduce peak flows from the drainage area served to predevelopment levels. It should be noted, however, that bioretention methods require modification of existing site grading practices to provide sheet flow as a runoff conveyance rather than traditional pipe inlet systems.



Schueler,l987.

Figure 4-11. Vegatative filter strip between developed area and *sensitive aquatic habitat.*

Scope/Applicability

Vegetative filter strips can be used on low- and medium-density residential and campus-type office or industrial sites where the percentage of pervious area is sufficient to promote infiltration and filtering. They are often used to convey sheet flow runoff to other conveyance or detention systems. Contributing drainage areas should be less than 10 acres in size with gentle slopes so that runoff arrives at the site in the form of overland sheet flow.

Vegetative filter strips are useful as buffers between developed areas and sensitive aquatic habitats such as wetlands, streams, and lakes and can be useful in stabilizing stream banks. Vegetative filter strips are adaptable to most climates and are effective where dense vegetation can be sustained on a year-round basis. They are not feasible in densely developed urban areas, where there are high percentages of impervious surfaces, or where discharge rates are high and flow is concentrated. A vegetative filter strip used for protecting a natural waterway in a commercial construction setting is shown in Figure 4-12.

Design Criteria Considerations

- Contributing areas of less than 10 acres.
- Uniform, even contributing slope of less than 5 percent.
- Length of no less than 50 to 75 ft with an additional 4 ft for every increase in slope of 1 percent.
- Width of no less than 20 ft.
- Development and maintenance of dense erosion-resistant vegetation species.
- Use of a level spreader at the top of the filter strip to distribute flow easily.
- Layout of the top edge of the filter strip on contour.
- Use of native vegetation.

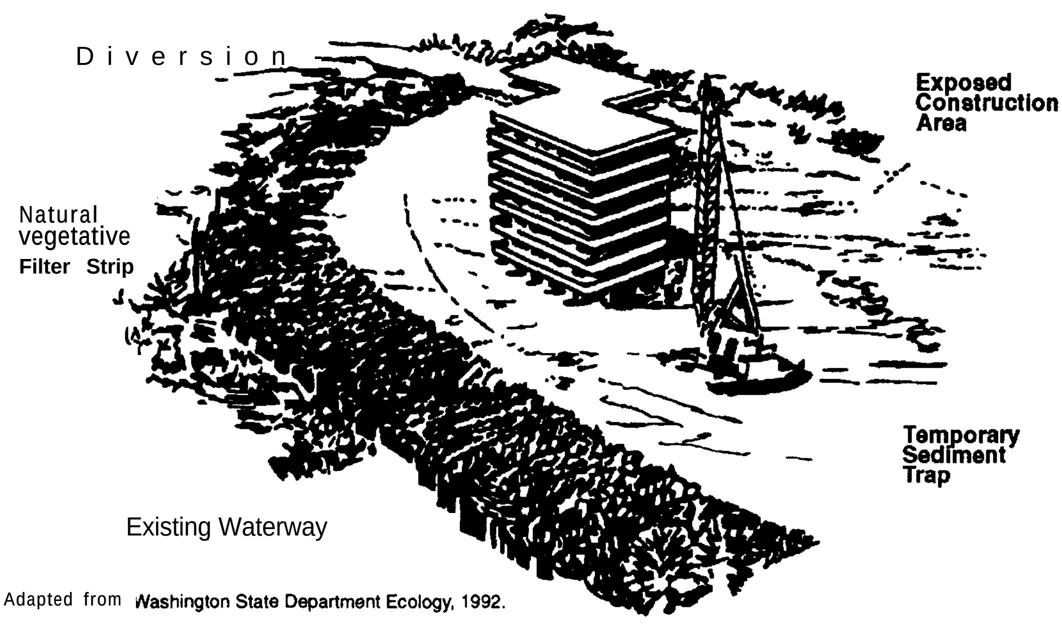


Figure 4-12. Vegatative filter strip.

Potential Impacts to Wetlands

Benefits

- Reduction of stormwater sediment and pollutant loads to adjacent and downstream wetlands.
- Potential recharge of groundwater, benefiting adjacent baseflow-dependent wetlands.
- Provide a buffer between wetlands and adjacent development.

Limitations

- Primarily function as a water quality BMP and might not adequately attenuate concentrated peak stormwater flows to adjacent or downstream wetlands.

Maintenance Requirements

Frequent inspections and maintenance are required in the first few years after filter strip construction while vegetation becomes established. Watering, fertilizing, and reseeding might be required during the initial establishment of the strip to maintain a dense vegetative cover. Established filter strips should be inspected on an annual basis for foot or vehicular damage. Inspectors should note encroachment, gully erosion, density of vegetation, and evidence of concentrated flows through or around the strip. A filter strip and its associated level spreader, when used, should be inspected periodically during storms to ensure that flow is not concentrating and short circuiting through the strip.

Vegetated filter strips require periodic repair, regrading, and sediment removal to prevent channelization. Sediments accumulating near the top of the strip should be removed to maintain the original grade. Longer buffer strips present the option of management as a lawn, or as a succession of vegetation types from grass, to meadow, to second-growth forest. ‘Natural” filter strips require less maintenance than grass lawns; however, corrective maintenance is still required to prevent the formation of concentrated flows. Shorter strips are managed as a lawn or as a short grass meadow and are mowed two or three times a year to suppress weeds and woody growth.

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Structural BMPs - Vegetated Natural Buffers

Definition/Purpose

Vegetated buffer areas are barriers of natural or established perennial vegetation managed to reduce the impact of development on the water quality of adjacent areas. They are effective in separating incompatible land uses and in displacing activities that represent potential sources of nonpoint source pollution from adjacent wetlands or water bodies. Vegetated buffer areas can be spatially arranged in linear strips or as free forms depending on site characteristics.

Vegetated buffer areas function primarily as water quality BMPs and usually do not provide adequate detention to reduce peak discharges to predevelopment levels. They reduce the velocity of surface runoff from adjacent developed sites and provide area for infiltration of runoff into the soil. Reduced flow velocities result in the removal of particulate contaminants through sedimentation and reduce the potential for channel erosion or degradation. Vegetated buffer areas can also reduce runoff velocities and contribute to groundwater recharge.

Scope/Applicability

Vegetated buffer areas can be used in large-lot, medium- to low-density single-family subdivisions or campus-type office or industrial sites where the percentage of pervious area is sufficient to promote infiltration. Vegetated buffer areas should be located in areas with gentle slopes where runoff is conveyed in the form of sheet flow. They are useful in separating incompatible land uses, and they can be effective in protecting sensitive habitats such as wetlands, streams, lakes, and shorelines from the impacts of adjacent development. Vegetated buffer areas are also useful in combination with other structural BMPs. An example of a vegated buffer is shown in Figure 4-13.

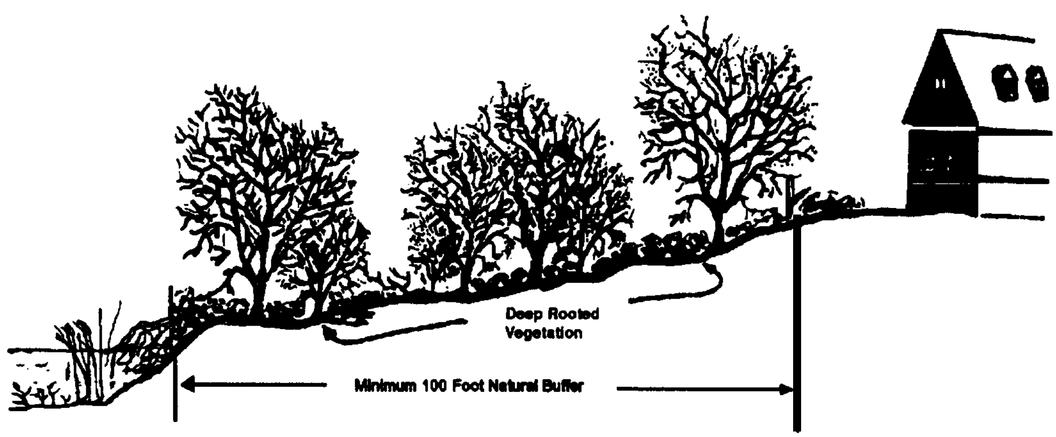
Design Criteria Considerations:

- Avoid compaction of the soils.
- Consider slope, vegetation, soils, depth to impermeable layers, runoff sediment characteristics, type and quantity of stormwater pollutants, and annual rainfall when determining buffer widths.
- Combine vegetated buffer areas with other structural or nonstructural BMPs as pretreatment where discharge rates are high or flows are concentrated.
- Slope of less than 5 percent.
- Increased buffer width as slope increases.
- Intermixed zones of vegetation (particularly, native vegetation) including grasses, deciduous and evergreen shrubs, and understory and overstory trees.

Potential Impacts to Wetlands

Benefits

- Reduction of stormwater sediment and pollutant loads to adjacent and downstream wetlands.
- Potential recharge of groundwater, benefiting adjacent baseflow-dependent wetlands.
- Provide a buffer between wetlands and adjacent land uses.
- Provide critical habitat adjacent to wetlands.



Adapted from State of Maine, DEP. 1992.

Figure 4-13. Vegetated natural buffer.

Limitations

- Primarily function as a water quality BMP and typically do not adequately attenuate concentrated peak stormwater flows to adjacent or downstream wetlands.

Maintenance Requirements

The inspection and maintenance of vegetated buffer areas are most important during the period of initial establishment. Maintenance requirements during the first few years of establishment include weed suppression and rodent protection in forested areas. Extra watering, fertilizing, and grass reseeding or tree replacement might also be necessary Trees might need to be staked to increase their survival rates. The condition of vegetated buffer areas should be inspected periodically, especially after heavy runoff events, during the first few years after buffer area creation to ensure that vegetation is healthy and that channelized flows are not developing.

Maintenance requirements are relatively minimal once a vegetated buffer area is estab lished. Routine maintenance is designed to promote the growth of dense, vigorous vegetation and includes mowing, litter removal, repair of eroded areas, and spot vegetation repair. Sediments that accumulate more than 6 inches at any spot should be removed. Watering and possible fertilization might also be required periodically.

Established buffer areas should be inspected on an annual basis for foot or vehicular damage. Inspectors should note encroachment, gully erosion, density of vegetation, and evidence of concentrated flows through or around the vegetated buffer area. A plan view of the use of natural vegatated buffers to protect riparian wetland areas is shown below in Figure 4-14.

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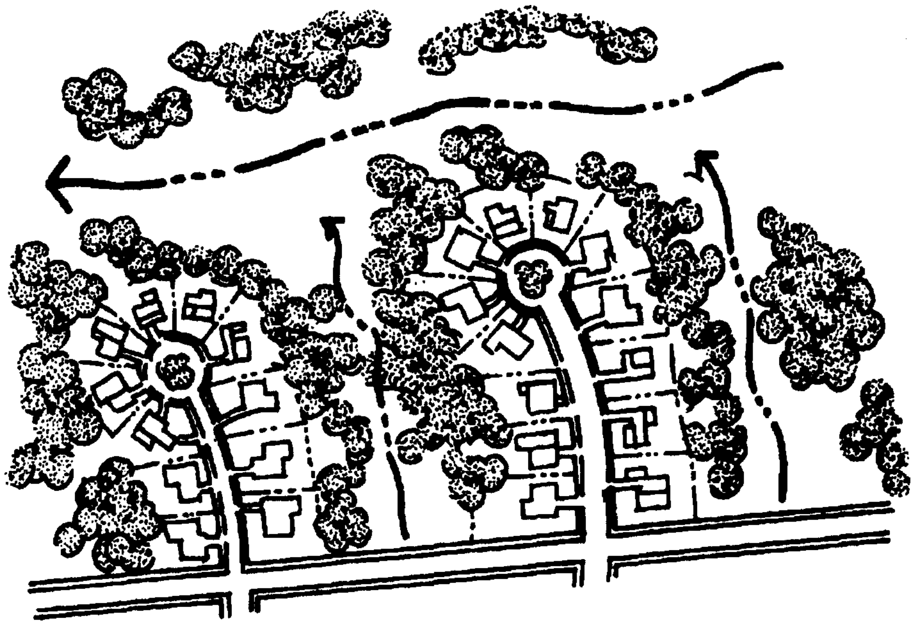

Schueler, 1987.

Figure 4-14. A plan view ofnatural vegatated buffer use.

Structural BMPs - Open Spaces

Definition/Purpose

Open spaces are grassed or wooded areas located within development sites to increase pervious area. Open spaces function primarily as water quality BMPs and usually do not provide adequate detention to reduce peak discharges to predevelopment levels.

Open areas reduce the velocity of surface runoff, resulting in an increased contact time of sheet flow with the soil and vegetative surfaces. Reduced flow rates result in the removal of particulate contaminants through sedimentation and reduce the potential of channel erosion or degradation. Reduced flow velocities can improve water quality by increasing infiltration, filtration, and adsorption of stormwater runoff on a site. Groundwater recharge can also occur as the result of increased infiltration in open areas.

Scope/Applicability

Open areas can be used in locations with gently sloping topography where runoff is conveyed in the form of sheet flow. They should be located in well-drained or moderately well-drained soils where offsets to the water table or bedrock exceed 4 ft. Open areas can be incorporated into lightly used recreational areas, or they can be maintained as meadows or wooded areas. Open areas should not be located in heavily used areas because of the potential for soil compaction, which could result in decreased infiltration rates on the site. An example of the use of open space to maximize the preservation and protection of wetlands and other aquatic resources is shown in Figure 4-15.

Design Criteria Considerations:

- Contributing slopes of less than 5 percent.
- Conveyance of runoff in the form of sheet flow.
- Locate in well-drained or moderately well-drained soils.
- Minimum water table and/or bedrock offset of 4 ft.
- Adequate size of open area to provide sufficient levels of treatment.

Potential Impacts to Wetlands

Benefits

- Reduction of stormwater sediment and pollutant loads to adjacent and downstream wetlands.
- Potential recharge of groundwater, benefiting adjacent baseflow-dependent wetlands.
- Provide a buffer between wetlands and adjacent development.

Limitations

- Primarily function as a water quality BMP and might not adequately attenuate concentrated peak stormwater flows to adjacent or downstream wetlands.

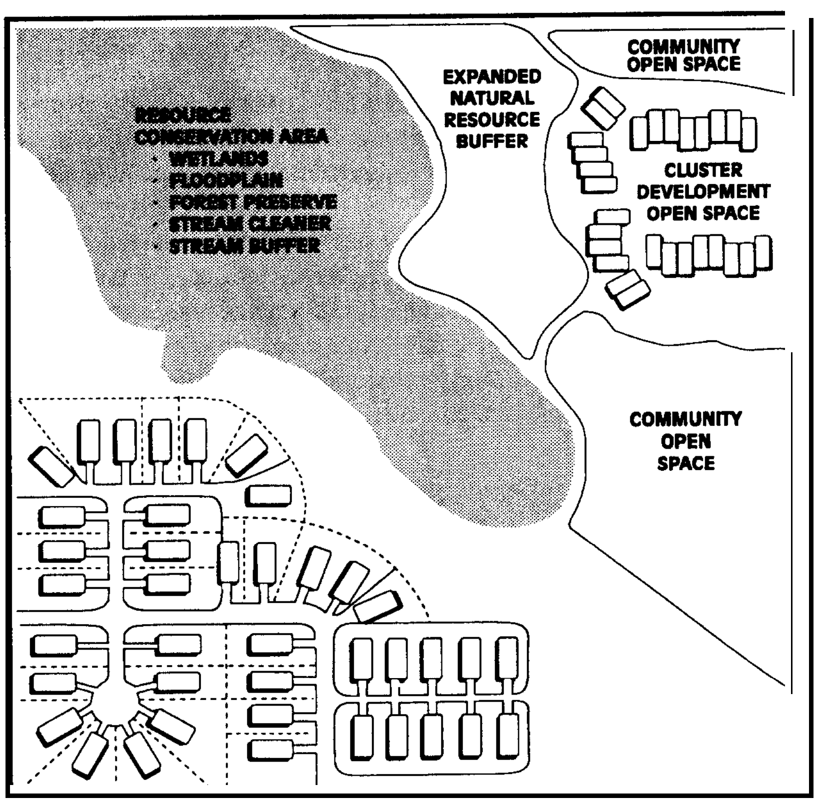

Figure 4-1.5. A plan view for maximizing the preservation and protection ofwetlands.

Maintenance Requirements

The maintenance of open spaces is minimal once the vegetation is established. Frequent inspections are required during the first few years to ensure a healthy, dense growth of the desired forms of vegetation. Extra watering, fertilization, and reseeding might be required. Forested areas might require weed suppression, rodent protection, watering, or staking to increase the survival of trees and shrubs during the first few years after establishment. Cutting and spraying with approved herbicides might also be necessary to remove unwanted vegetation.

Open spaces should be inspected on an annual basis for damage by foot or vehicular traffic, encroachment, gully erosion, and vegetation density. The effectiveness of the open space will decrease over time as sediments accumulate. Inspectors should look for accumulated sediments so that they can be removed before they damage vegetation. Routine maintenance includes removal of trash and debris, repair of eroded areas, spot repair of vegetation, and mowing of the grass.

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Structural BMPs - Extended Detention Dry Basins

Definition/Purpose

Extended detention dry basins temporarily store stormwater runoff from a site and release it at a controlled rate by use of a fixed outlet. They are designed not to have permanent standing water and are usually dry between storm events. Extended detention dry basins control water quantity by temporarily detaining stormwater, and they reduce downstream channel erosion by reducing the frequency of bankfull and subbankfull flooding events. Extended detention dry basins provide some water quality benefits by removing pollutants primarily through the settling of suspended solids. They are designed and located to collect stormwater runoff from drainage areas and to control peak discharges for one or more design storm frequencies.

Scope/Applicability

Extended detention dry basins can be used in locations with sufficient open space and proper topography to allow gravity flow of stormwater to the basin and sufficient storage without backup into surrounding areas. They can be used in combination with Permanent Pools, or they can incorporate shallow marsh habitat in the normally inundated areas near their outlet pipes to enhance pollutant removal. Extended detention dry basins are best suited for contributing drainage areas of over 30 acres and are not usually practical for areas less than 10 acres in size. The natural hydrologic conditions and characteristics of adjacent or downstream wetlands shou1d be considered in the design and placement of extended detention dry basins so that impacts to these existing systems can be minimized. See Figure 4-16.

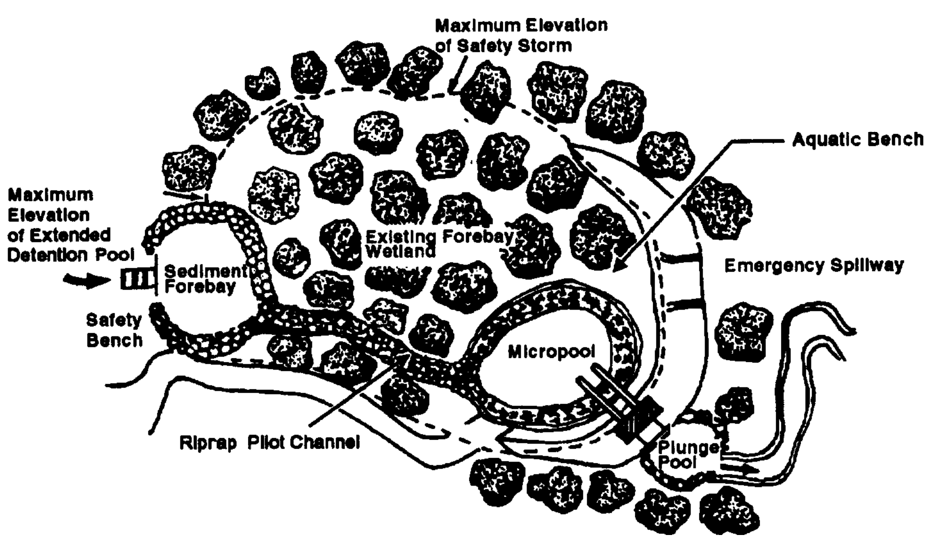
Design Criteria Considerations

- Detention of the 2-year, 24-hour design storm for at least 40 hours with release at a rate no greater than 50 percent of the predevelopment peak rate.
- Sufficient storage for sedimentation to be effective before water leaves the basin.
- Length-to-width ratio of 3:l if possible.
- Sufficient pond depth and cross-sectional area to establish low flow velocities.
- Minimum slope of 2 percent on basin floors.
- Minimum resuspension by reducing inflow velocities.
- Native plants.

Potential Impacts to Wetlands

Benefits

- Potential recharge of groundwater from extended detention ponds, benefiting baseflow dependent wetlands.
- Reduction of stormwater sediment loads to downstream wetlands.
- Potential reduction in the amount of stormwater associated pollutants entering downstream wetlands.
- Reduction in the first-flush impact of stormwater runoff to downstream wetlands.



Adapted from MWCOG, 1992.

Figure 4-46. Schematic of an enhanced dry extended detention pond system designed to accommodate protection ofexisting wetlands.

- Elimination of the need for a permanent pool with habitat destruction potential.
- Potential for the creation of high marsh or wet meadow wetlands within the extended detention ponds through the incorporation of micropools.
- Potential for the incorporation of complex boundaries and microtopography in the pond design to enhance diverse vegetation and habitat.
- Reduction in the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.

Limitations

- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as the result of rerouting and detention.
- Embedding of downstream wetland substrates as the result of the removal of coarse sediments.
- Changes to adjacent natural wetland hydroperiods.
- Smothering of wetlands incorporated into extended detention ponds as a result of increased sedimentation.
- Thermal impacts to downstream wetlands resulting from the discharge of water from extended detention ponds.
- Low habitat diversity and limited structure of wetlands created in extended detention ponds.

Maintenance Requirements

Extended detention dry basins can have relatively high maintenance burdens and costs. Extended detention dry basins will not achieve their intended purpose unless routine and non-routine maintenance tasks are performed on schedule. Responsibilities for maintenance need to be clearly defined, maintenance schedules enforced, and regular inspections performed. Routine maintenance includes mowing, debris and litter removal, erosion control, and the control of nuisances.

Extended detention dry basins should be inspected on an annual basis to ensure that they continue to operate as designed. The inspector should measure and record the drainage rate of water after a storm to check that the design detention times are met. The flow control device should be inspected regularly for evidence of clogging or too rapid release. In general, the extended detention dry pond should be inspected for structural soundness, sediment accumulation, broken or missing parts, and trash and debris accumulation. The side slopes should be inspected for rodent holes, tree growth, subsidence, erosion, and cracking. The spillway should be inspected for clogging or missing rocks. The pilot channel to the upper stage, the flow path to the lower stage, and the channel upstream and downstream of the basin should be checked for erosion damage. The forebay/riser should be checked for sediment accumulation. Figure 4-17 indicates typical locations for necessary maintenance access.

Trash and debris should be removed from the site. Trash should be removed from the debris barriers when greater than 20 percent of the openings in the barrier are plugged, and it is especially important to remove floatable debris to prevent clogging of the control device or riser.

The grass/ground cover of basins located in nonresidential areas should be moved at least twice a year to control weeds and to discourage the growth of woody vegetation. Extended detention dry basins located in residential areas require more frequent mowing. Dense vigorous growth should be maintained on the bottom as well as on the sides of the extended detention dry pond. The side slopes, emergency spillway, and embankment might also require periodic stabilization from erosion damage.

Nonroutine maintenance includes the removal of accumulated sediments from the basin. Accumulated sediments reduce the performance of an extended detention dry basin by gradually reducing its capacity to treat stormwater, and by clogging the orifice or filter medium. After sediments are removed, the area should be stabilized immediately with vegetation to prevent sediments from clogging the control device. Other nonroutine maintenance activities include the eventual replacement of the inlet, outlet, and riser works.

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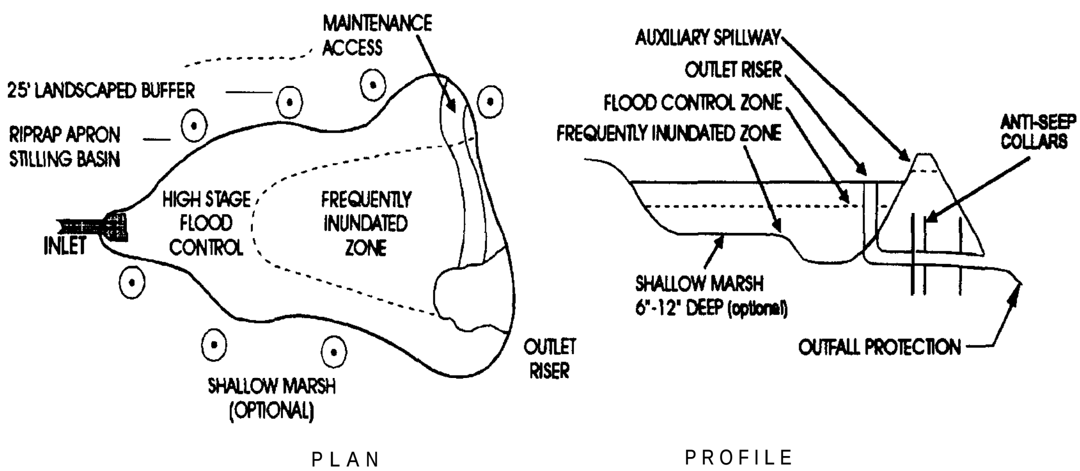

Adapted from Milone & MaBroom, Inc.. 1991.

Figure 4-17. Schematic of dry pond showing maintenance features.

Schueler, TX., P.A.. Kumble, and M.A.. Heraty. 1992. *A current assessment of urban best management practices, techniques for reducing non-point source pollution in the coastal zone.* Prepared for the Metropolitan Washington Council of Governments, Washington, DC.

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Structural BMPs- Wet Ponds

Definition/Purpose

Wet ponds are depressions constructed by excavation and embankment procedures to store excess runoff temporarily on a site. After a runoff event, overflow from the pond is released at a controlled rate by an outlet device designed to release flows at various peak rates and elevations until the design elevation of the pool is reached Wet ponds maintain a permanent pool of water between storm events. Wet ponds are located to collect stormwater inflows from adjacent drainage areas and are usually designed to control peak discharges from relatively large design storms.

Wet ponds regulate stormwater runoff from a given rainfall event by the temporary storage of peak flows in order to mitigate quantity and quality impacts to downstream systems. Pollutant removal in wet ponds results from the gravity settling of sediments/pollutants, the chemical transformation and biological uptake of nutrients while water is detained in the pond, and the infiltration of soluble nutrients through the soil profile. Extended detention time in the permanent pool of wet ponds allows for increased sedimentation, transformation, and flocculation of pollutants in the system. Decreased runoff rates from wet ponds reduce downstream channel erosion and resultant sediment pollution. Wet ponds have been shown to be the most efficient means of water quality protection when compared with other conventional BMPs.

Scope/Applicability

Wet ponds can be located in areas that have topographic conditions that allow for the gravity flow of stormwater and enough open space to allow sufficient sizing of the structure so that it can adequately treat expected flows. Wet ponds can be used in low- and high-visibility locations where contributing watersheds are greater than 10 acres in size or where continuous baseflows exist to ensure dry-weather flow. They are not useful in arid regions where evapotranspiration exceeds rainfall, and their use is limited in areas where space is a constraint such as densely developed urban localities. Wet ponds have been used in combination with wetlands and other extended detention treatment methods. An extended detention wet pond is shown in Figure 4-18.

design Criteria Considerations

- Extended detention of a l-inch storm for 24 to 40 hours.
- Permanent pool volume of at least 2.5 times the runoff volume generated by the mean storm.

- Sufficient volume in the permanent pool to allow for low-energy settling of sediments between storms.
- Use of pond liners in high-permeability soils.
- Length-to-width ratio of 3:1 with a wedge shape.
- Watershed area greater than or equal to 10 acres.
- Access for maintenance equipment.
- Enhanced conditions for biological treatment between storms (i.e., native vegetation in shallow ponds).
- Inlet and outlet pipes set to discharge at or below the permanent pool surface.
- Stone riprap lining, plunge pools, energy dissipators, or other acceptable means should be used below the pond outlet to prevent scouring.

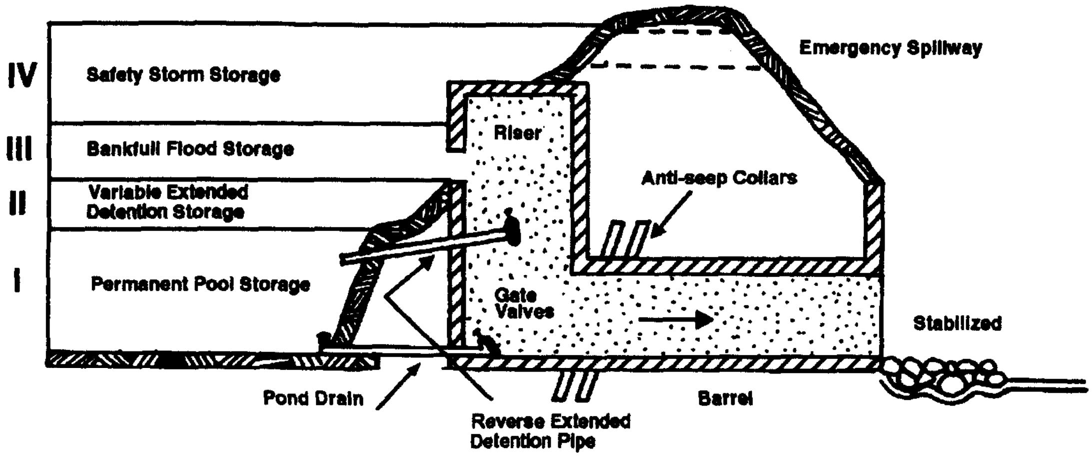
Potential Impacts to Wetlands

Benefits

- Potential for the creation of emergent and high marsh-wetlands within the wet pond.
- Reduction of stormwater sediment loads to downstream wetlands.
- Potential for the incorporation of designs to enhance diverse vegetation and habitat.
- Reduction in the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.

Limitations

- Changes to the natural hydroperiod of adjacent natural wetlands.
- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as the result of rerouting and detention.



Adapted from Schueler. 1992.

Figure 4-18 Conceptual cross section view of an extended detention wet pond.

- Potential for the introduction of pollutants to downstream wetlands during peak storm events.
- Embedding of downstream wetland substrates as the result of the removal of coarse sediments.
- Strong shifts in the trophic status of downstream communities.
- Thermal impacts to downstream wetlands resulting from the discharge of water from wet ponds.
- Low habitat diversity and limited structure of wetlands created in wet ponds.

Maintenance Requirements

Maintenance requirements for wet ponds are relatively modest. Long-term performance will be degraded, however, by the buildup of sediments. Therefore, a firmly established maintenance and inspection program is required. Routine maintenance includes inspections, mowing of the embayment and buffers, and the removal of trash and debris from the forebay.

Wet ponds should be inspected on an annual basis to ensure that they continue to operate as designed. The inspector should monitor the water level after a storm to compare pond performance against the design detention time. Other factors that contribute to the performance of the pond that should be inspected are related to structural soundness, sediment accumulation, appearance, security, and the ease of maintenance. The side slopes should be inspected for rodent holes, tree growth, subsidence, erosion, and cracking. The barrel, spillway, and drain should be inspected for clogging, and the forebay/riser should be checked for sediment accumulation. The adequacy of the erosion protection measures for the channel upstream and downstream of the basin should be noted, as well as any modifications that have occurred to the contributing watershed or pond structure.

Trash and debris should be removed from the site as part of the periodic mowing regimen. Maintaining a neat appearance at the site helps to discourage vandalism and illicit dumping. All floatable debris around the riser should be removed, and the outlet should be checked for possible clogging.

Mowing of the upper stage, side slopes, embankment, and emergency spillway is required at least twice a year to prevent woody growth and the excessive growth of weeds. More frequent mowing is required if the wet pond is located in a residential neighborhood. A dense vigorous growth of grass or ground cover should be maintained around the wet pond. The side slopes, emergency spillway and embankment might also require periodic stabilization from slumping and erosion damage.

Nuisances associated with problem wet ponds include insects, weeds, odors, and algae. Algae and mosquitoes can be controlled by the introduction of fathead minnows and other fish. This practice is preferred over chemical application, especially in the case of ponds that discharge to wetlands. Excessive growth of emergent, floating, and submerged vegetation can be mechanically harvested or controlled with herbicides.

Nonroutine maintenance includes the removal of accumulated sediments from the basin. Accumulated sediments reduce the performance of a wet pond basin by gradually reducing its capacity to treat stormwater. Wet ponds require sediment removal when the storage capacity of the permanent pool is significantly reduced.

Actual sedimentation rates depend on the size, degree of construction, and land use in the watershed. Other nonroutine maintenance includes structural repairs and the replacement of various inlet/outlet and riser works.

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Structural BMPs - Constructed Weltands

Definition/Purpose

Constructed wetlands are shallow pools constructed on nonwetland sites as part of the stormwater collection and treatment system. They provide growing conditions suitable for the growth of emergent marsh plants. These systems are designed primarily for the purpose of stormwater management and pollutant removal from surface water flows. They are essentially a type of wet pond with greater emphasis placed on vegetation and depth/area considerations. Constructed wetlands are often used in sequence with a sediment basin, a forebay, or some type of stormwater pond.

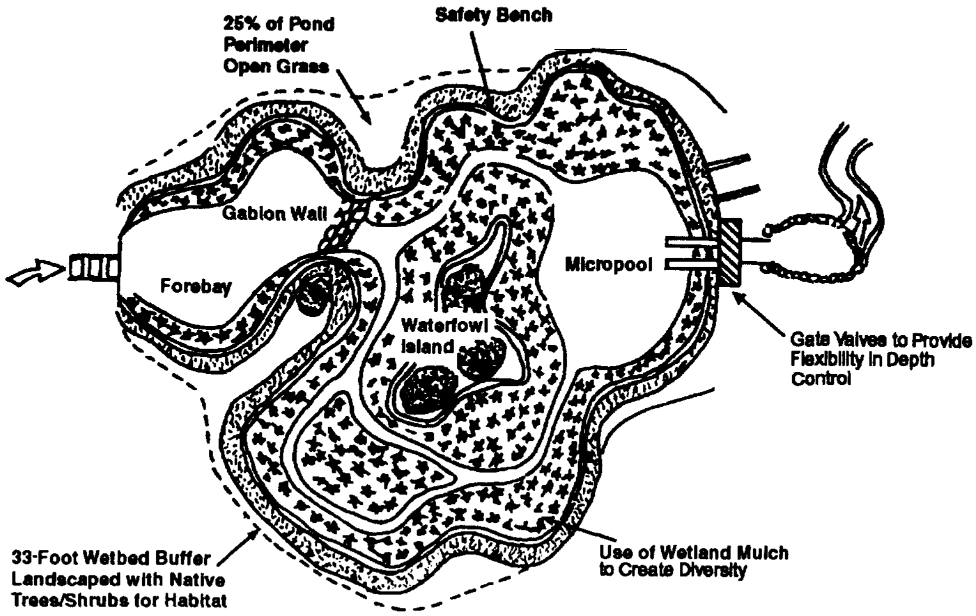
Constructed wetlands are designed to maximize removal of pollutants from stormwater through physical, chemical, and biological mechanisms. They can be designed to store stormwater runoff temporarily, thereby lowering stormwater quantity and quality impacts on receiving systems including lakes, water supply reservoirs, streams, wetlands, and recharge aquifers for water supply wells. Physical mechanisms of pollutant removal include sedimentation, filtration, and volatilization. Chemical mechanisms include precipitation, adsorption to sediments, flocculation, and transformations such as reduction. Biological mechanisms include plant and bacterial nutrient uptake. Constructed wetlands can also be designed to allow for a wide diversity of plant species and improved wildlife habitat.

Scope/Applicability

Constructed wetlands can be used in locations with sufficient open space and appropriate topography to allow gravity flow of stormwater and sufficient sizing of the structure to adequately treat expected flows. They can be applied to most sites, including those with large pollution and runoff loads, provided sufficient baseflow is available to maintain proper hydrology to support wetland vegetation. Constructed wetlands might be useful as a retrofit for older dry stormwater basins. It is important to remember that the hydrology of the watershed draining to the constructed wetland must be capable of supporting the wetland. A schematic of a constructed wetlands pond is shown in Figure 4-19.

Design Criteria Consideration

- Volume should accommodate at least a 6-month, 24-hour storm for the watershed's developed condition.
- Wetland area should be greater than or equal to 2 percent of the watershed area.
- Watershed of 5 acres or more.
- Length-to-width ratio of 3:l or greater; if this is not feasible, use baffles.
- Vary water depth, with approximately 50 percent of the area about 0.5 ft deep and with some open water, to provide diverse habitat.
- Dry season baseflow must be adequate for vegetation maintenance, with evapotranspiration considered.
- Minimize short circuiting by using baffles, islands, and peninsulas to ensure a long distance from inlet to outlet.
- Incorporate islands to provide habitat and refuge for birds.
- Plant and soil pollutant removal effectiveness may vary with ***season.***
- Consider soil permeability and groundwater conditions. Lining may be necessary.
- Organic soils provide best nutrient retention and plant substrate.
- Vegetation should be selected for hydroperiod, climate, resistance to contaminants, stem density (to promote sedimentation), and habitat value. Consider native vegetation.
- Consider plant uptake/release of nutrients and contaminants, and possible plant harvesting.
- Use of forebay or other controls in "treatment train" design to pretreat runoff.
- Erosion control should be employed in the forebay and at the outlet, preferably with vegetation.
- Design for easy maintenance.
- Provide access for maintenance equipment.



Schueler. 1992.

Figure 4-19. Schematic design ofconstructed wetland for stormwater control with an enhanced shallow marsh system.

Potential Impacts to Wetlands

Benefits

- Reduction of flooding and erosive velocities and stormwater sediment loads to adjacent and downstream wetlands.
- Potential for the incorporation of designs to enhance diverse vegetation and wildlife habitat in urban areas.
- Reduction in the potential for downstream wetland degradation resulting from erosion associated with peak stormwater flows.

Limitations

- Changes to the natural hydroperiod of adjacent natural wetlands.
- Reduction in the amount of surface water supplied to adjacent or downstream wetlands as the result of rerouting and detention.
- Smothering of vegetation in constructed wetlands resulting from sedimentation.
- Potential for the introduction of pollutants to downstream wetlands during peak storm events.
- Embedding of downstream wetland substrates as the result of the removal of coarse sediments.
- Thermal impacts to downstream wetlands resulting from the discharge of water from constructed wetlands.

- Potential takeover of vegetation by invasive aquatic nuisance plants.
- Potential for blocking fish passage if constructed in stream channel.

Maintenance Requirements

Maintenance requirements for constructed wetlands receiving stormwater are high during the first several years while vegetation is being established. Reinforcement planting and erosion control BMPs might be necessary. Maintenance during the establishment phase involves frequent inspection for erosion damage or subsidence on the embankment or spillway. Rills formed through erosion should be filed and thoroughly compacted. It is important that the vegetated cover on the embankment and spillway be dense and healthy Mowing and fertilizing help promote vigorous growth of plant roots that resist erosion. Mowing also prevents the growth of unwanted woody vegetation.

Another type of maintenance that might be necessary during the initial growing season is protection of the first year wetland vegetation growing at the water's edge and on the side slopes from birds. Birds often feed on the carbohydrate-rich shoots of the young vegetation, a problem referred to as "eat-out."The problem can be addressed by surrounding the open water area of the constructed wetland with wire to limit access to the vegetation from the water, which is how the birds get to the vegetation. The wire should be maintained until the wetland vegetation is well established, which is usually by the second growing season.

Periodic inspections are necessary to ensure that the constructed wetland is operating as designed. Constructed wetlands should be inspected after major storms during the first year of establishment for the stability of banks and for flow channelization. For example, debris on plants or dead vegetation that has fallen over should be removed to minimize damage to other wetlands vegetation. Excessive accumulation of sediments in any part of the system should be noted as well as any changes to the contributing watershed. The inspector should pay special attention to the proper operation of pumps and water control structures, sealing, water level, flow distribution, and density of vegetation during the first years of operation. Water level is the most critical aspect of wetland plant survival within the first year after planting. Too much water is often a greater problem than too little because the roots of plants do not receive enough oxygen.

Routine maintenance of constructed wetlands includes repair of fences, mowing of sod/ ground cover on embankments, and removal of trash accumulated in trash racks, outlet structures, and valves. Burrowing animals may damage embankments and spillways. They can be discouraged by including a thick layer of sand or gravel on the fill or by installing a wire screen to inhibit burrowing. Organic matter accumulating in the wetland will eventually limit storage capacity and the capacity to treat runoff. Accumulation of organic matter can be reduced by harvesting of vegetation or seasonal drawdown to allow organic material to oxidize. Periodic sediment removal from the forebay is necessary

Mosquito problems are one of the more frequently cited drawbacks of constructed wetlands. Mosquitoes can be more of a problem in wetlands with tall cattails and bulrushes than those with lower-growing vegetative forms due to the protection from predators afforded by the taller plants. Cattails can be controlled by flooding for several weeks during the growing season after the stems have been cut (stems need to be cut below the water level). Biological control of mosquitoes can be enhanced by stocking the wetland with fish that are tolerant of low dissolved oxygen conditions. Mosquitoes can also be controlled through judicious application of mosquito larvicide using the optimum dosage level and applying only when larval density is high.

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Structural BMPs- Porous Pavement and Concrete Grid Pavement

Definition/Purpose

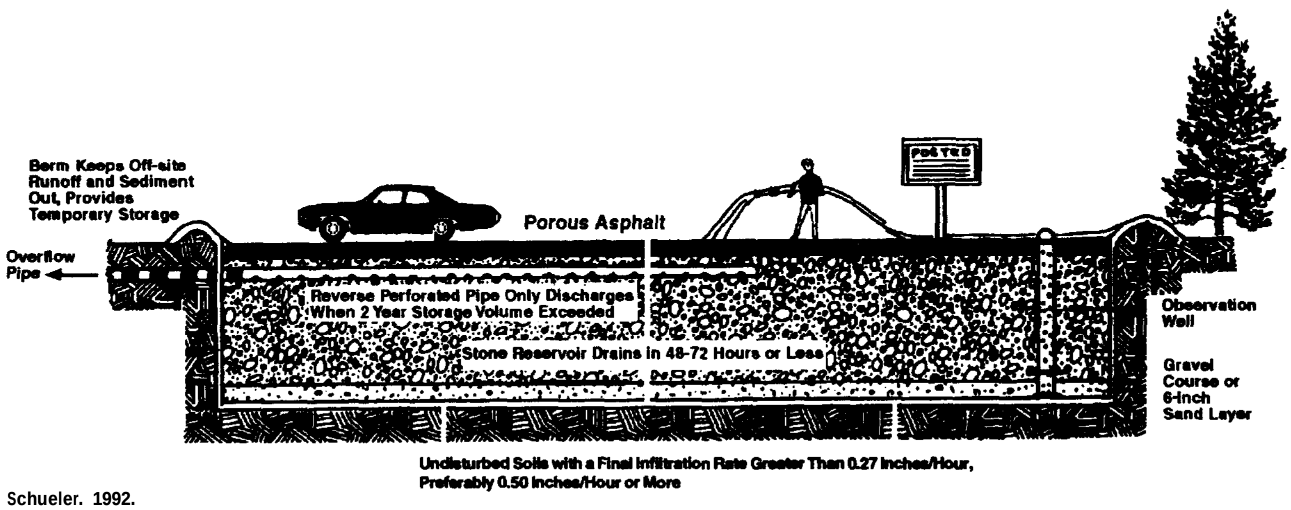
Porous pavement is an alternative to conventional pavement designed to minimize surface runoff. It may be constructed of asphalt or concrete and is similar to regular paving material except that a larger-sized aggregate is used in the asphalt or concrete mixture to provide a high-void course. Porous pavement is composed of four layers: the pavement course, the upper filter course, a stone reservoir, and a lower filter course and filter fabric lining over the underlying soil (see Figure 4-20).

A similar practice is concrete grid pavement, where modular, interlocking concrete blocks having openings are used (see Figure 4-21). Runoff that permeates the porous pavement surface enters an underground stone reservoir and gradually exfiltrates from the reservoir into the surrounding subsoil.

Porous pavement can help to restore or maintain predevelopment hydrology by reducing the volume of stormwater runoff produced after development relative to runoff volumes generated from roads and parking lots paved with conventional surfaces. By increasing the amount of infiltration, porous pavement can provide groundwater recharge, low flow augmentation, and stream bank erosion control through reduction of peak discharges. Pollutants are removed by absorption, straining, and microbial decomposition as stormwater seeps through the subsoil. Sediments and particulate-associated pollutants are removed in the underground stone reservoir. The use of porous pavement has added advantages in that it reduces land consumption, reduces or eliminates the need for curb and gutters and conveyance systems, and reduces the tendency of vehicles to hydroplane and skid. Other benefits can include storm detention and preservation of water supplies to the vegetation around parking areas.

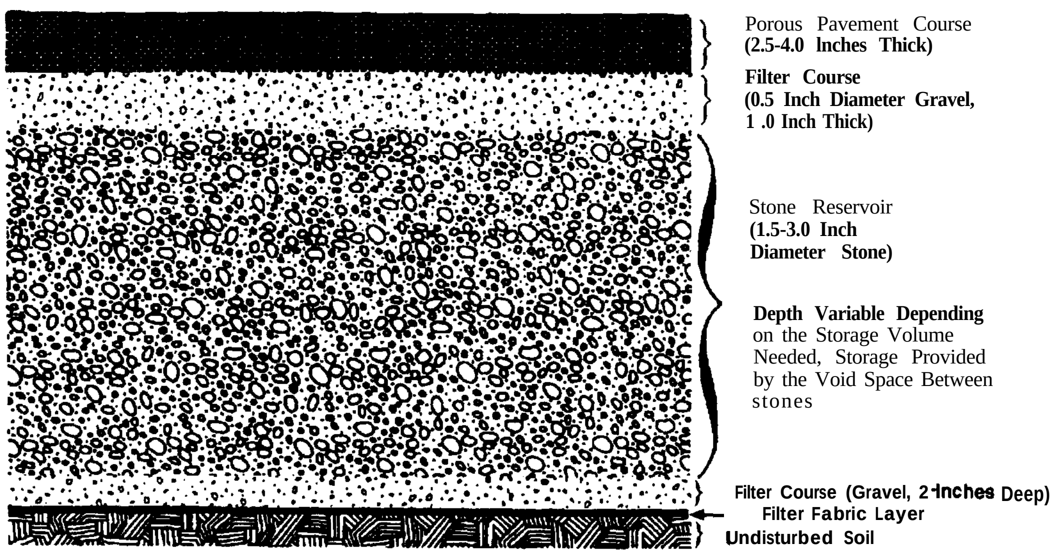
Scope/Applicability

The use of porous pavement is constrained to sites having deep and permeable soils, slopes less than 5 percent, restricted truck traffic, and suitable adjacent land uses. The use of porous pavement can also be restricted in regions with colder climates, arid regions or regions with high wind erosion rates, and areas having sole-source aquifers. It is generally used only for parking lots (between 0.25 acre and 10 acres in size) and lightly used access roads. Porous pavement is used when the size of the development, or the lack of available space, limits the use of other BMPs. It has limited retrofit capability because most soils in urbanized areas have been previously modified to the extent that they are not capable of providing adequate infiltration rates. Porous pavement, designed with an underdrain, can be used in areas where underlying soils, groundwater depth, or bedrock restrict the ability of runoff to be disposed of by infiltration. Porous pavement reservoirs with underdrains serve as underground detention facilities.



Schueler. 1992.

Detail of cross section.

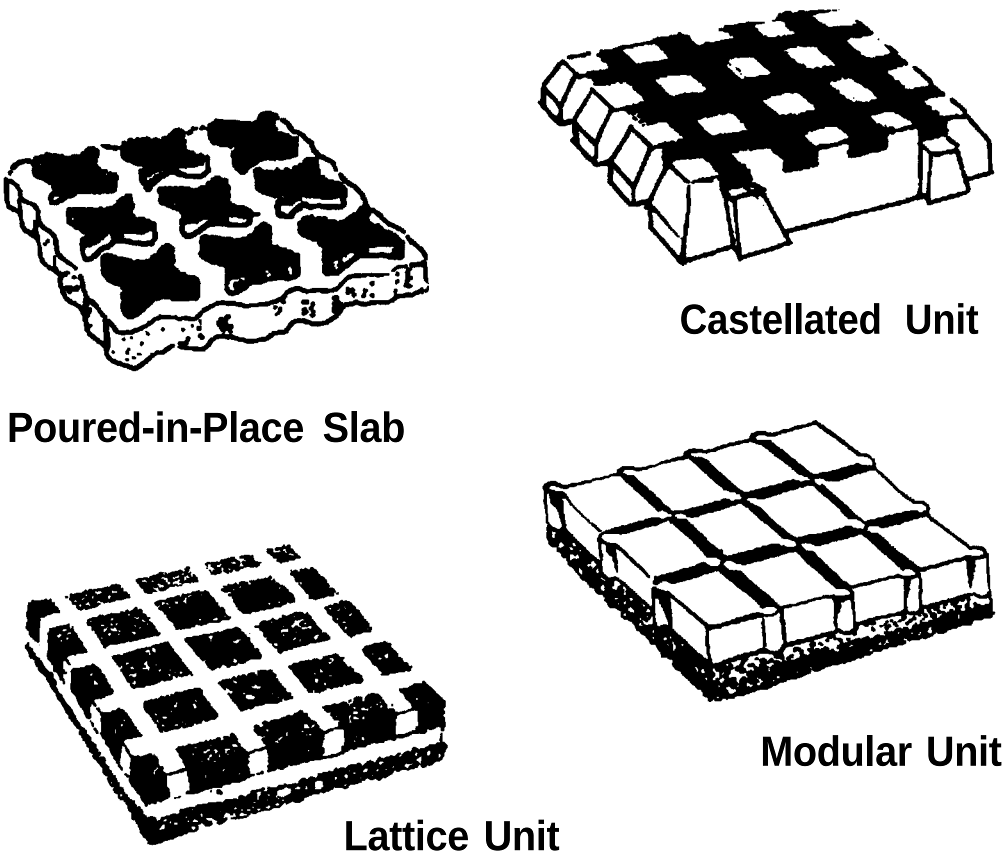


Schueler, 1992.

Figure 4-20. Schematic cross section of a porous pavement system with storage reservoir.

Design Criteria Considerations

- Field-verified infiltration rates greater than or equal to 0.5 inch per hour.
- Site area of less than 10 acres with minimal contributions of runoff from the surrounding watershed.
- Slopes less than 5 percent.
- Minimum clearance of 3 ft from the bottom of the system to the groundwater table.
- Filter fabric lining to prevent the upward piping of underlying clays.
- Reservoir of variable depth containing clean, washed, l- to 2-inch-diameter stone.
- Overlying filter course of 0.5- to l-inch gravel.
- Use of underdrains if well-drained conditions are lacking at a site.
- 20-ft-wide grass buffer around the pavement to filter pollutants from runoff contributed by adjacent areas, if applicable.



State of Washington, 1992.

Figure 4-21. Variations of concrete grid pavement.

Maintenance

Porous pavement requires quarterly vacuum sweeping and/or jet hosing to maintain porosity and prevent clogging. Sediments will accumulate where water is concentrated. These can be removed by a vacuum cleaning street sweeper equipped with a brush followed by jet hosing. Porous asphalt and concrete require no more additional maintenance than conventional paving materials. Buffer strips surrounding the pavement will need mowing. Surfaces paved with modular concrete blocks with open lattice might require mowing of grass growing up between the lattice. Mowing is seldom required in areas of frequent traffic. Poured-in-place concrete grid pavements can be plowed as long as the plow blade is set high enough to prevent damage to grass. Fertilizers and deicing chemicals should not be used on concrete grid pavement because these chemicals can damage the concrete. The application of abrasive material, such as sand or ash, in times of heavy snowfall should be avoided due to the potential for clogging of the surface.

Cleaning techniques are effective only in restoring porous pavement that has reductions in permeability of less than about 25 percent. Clogging may also be alleviated by drilling 0.5-inch holes through the pavement every few feet. If severe clogging should occur, complete replacement is required. Potholes and cracks can be repaired using conventional nonporous patching compounds as long as the cumulative area being patched is minimal.

Porous pavement should be inspected several times in the first few months after construction and annually thereafter. Inspections of the pavement should be scheduled after major storms so that areas of standing water can be identified. Water standing on the pavement might indicate local or widespread clogging. The condition of the buffer strips adjacent to the pavement should also be checked at the time of inspection.

Potential Impacts to Wetlands

Benefits

- Reduction in the amount of stormwater-associated pollutants entering adjacent wetlands.
- Reduction of stormwater sediment loads to adjacent wetlands.
- Reduction in the potential for adjacent wetland degradation resulting from erosion associated with peak stormwater flows.
- Potential recharge of groundwater from infiltration, benefiting adjacent baseflow-dependent wetlands.

Limitations

- Might not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.
- Possible reduction in the amount of surface water supplied to adjacent surface-flow-dependant wetlands as a result of rerouting.
- Not appropriate for high traffic areas or surfaces receiving frequent heavy vehicle traffic.

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Structural BMPs - Oil/Grit Separators or Water Quality Inlets

Definition/Purpose

An oil/grit separator or water quality inlet is an underground concrete vault that can have from one to three chambers. These structures are designed to remove sediments and hydrocarbons from stormwater runoff associated with roads and parking lots before it is discharged into the storm sewer system or an infiltration BMP. Several different designs, which vary in their purpose, removal mechanisms, space requirements, and stormwater retention capacities, are used. Some are designed simply for spill control and have limited capacity to treat the dispersed oil found in stormwater runoff from parking lots. Spill control oil/water separators consist of a chamber with a submerged orifice that allows the oil to float at the top of the chamber, where it can be removed.

Other separator designs have multiple chambers and use sophisticated equipment to remove oil from the surface and particles settled at the bottom. The American Petroleum Institute (API) oil-water separator and the Coalescing Plate Separator (CPS) are two designs used in the State of Washington. The hydraulic conditions for oil removal by the API separator are promoted by baffles. The CPI separator contains a series of fiberglass or polypropylene plates that promote the process of oil separation. Three-chambered oil/grit separators typically contain permanent pools of water and are designed to remove oils by providing long contact times with particles so that sorption onto particles will take place and the subsequent removal by gravity settling will occur.

A recently developed design in Canada includes a built-in diversion (bypass) structure. This feature allows 80 to 90 percent of all rain hours (typically considered to capture most "first flush” events) to enter the treatment chamber. The larger, problem-causing (flushing) storms (10 to 20 percent of all rain hours) are diverted around the treatment chamber.

Oil/grit separators are used to remove oil, grease, trash, and debris from runoff originating from heavily trafficked areas such as gas stations, public works, transportation maintenance facilities, industrial yards, loading areas, or other areas where hydrocarbon pollutant loads are expected to be significant. Water quality inlets are frequently used to pretreat runoff before it is conveyed through the storm drain network, or before treatment by a local infiltration BMP such as an infiltration trench. Oil/grit separators provide minimal groundwater recharge, low flow augmentation, peak runoff attenuation, or stream bank erosion control benefits. Figure 4-22 shows two views of a typical oil/grit separator.

Scope/Applicability

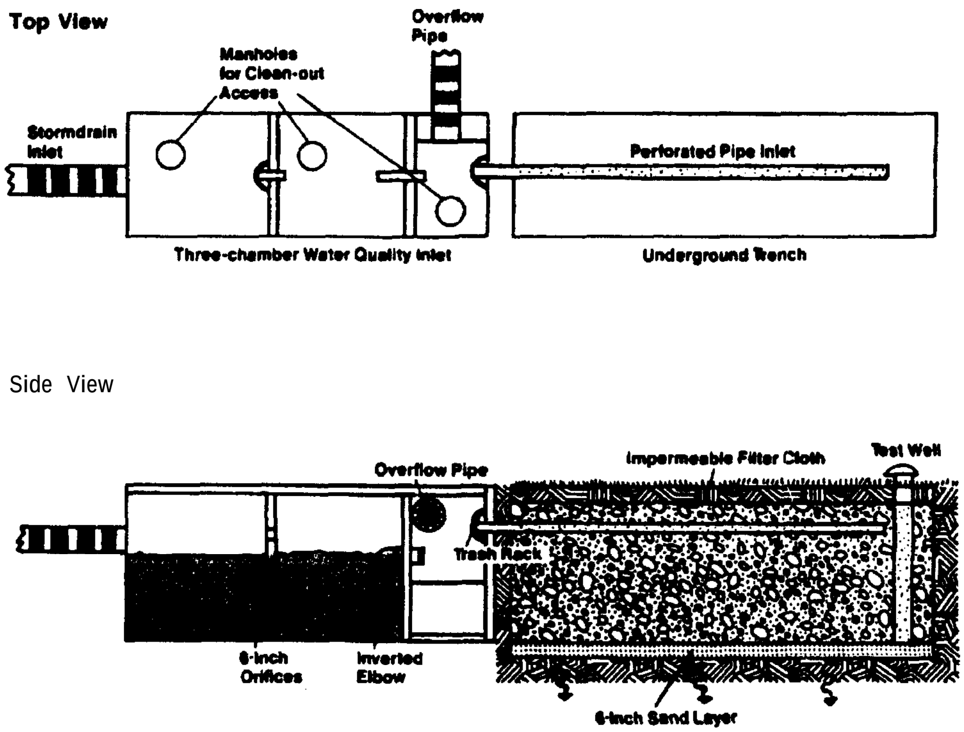
Oil/grit separators, when used alone, are restricted to highly impervious catchments of small size (less than or equal to 2 acres) such as service stations, parking lots, convenience stores, and fast food outlets. Oil/grit separators are adaptable for use in all regions of the country and are frequently used as part of a series of BMPs. They are commonly used as pretreatment devices for infiltration BMPs. Oil/grit separators can also be used as a pretreatment device for pond-type BMP systems, to prevent oily sheens from developing on pond surfaces, and to remove trash.

Design Criteria Considerations

- Typically serve an area of less than 1 acre.
- Horizontal velocity less than 3 ft per minute or 15 times the rise rate, whichever is smaller.
- Depth 3 to 8 ft.
- Width 6 to 16 ft.
- Use of baffles to prevent resuspension.
- Removal covers that allow access for observation and maintenance.
- Maximum pool volume in three chambered separators in the first and second chamber. Chambers should be sized to provide at least 400 ft of wet storage per contributing acre.
- Use of trash racks welded to the end plates between the first and second chambers in multiple-chambered separators.
- Upstream flow control to prevent the flushing of accumulated pollutants during major storms.

Maintenance

Although the structural failure rate of water quality inlets is very low relative to other stormwater treatment devices, regular removal of accumulated sediments and debris is critical to achieving any degree of pollutant removal effectiveness. Material that accumulates in the oil/grit separator must be removed promptly or it might be flushed from the device during the next storm, resulting in a pulse of highly concentrated contaminants to receiving waters. Cleanouts should be performed at least twice a year, and weekly inspections are recommended. Separators should be cleaned in time for the rainy season and after the first storm of the season.



Schueler, 1987.

Figure 4-22. Two views of an oil/grit separator.

Limitations

- Primarily function as a water quality BMP and might not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.
- Possible reduction in the amount of surface water supplied to adjacent surface-flow-dependent wetlands as a result of rerouting.
- Potential negative impacts to adjacent or downstream wetlands from pollutants associated with improperly maintained separators.

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Strutural BMPs -Level Spreaders

Definition/Purpose

A level spreader is a hydraulic device used to convert channelized flows from an outlet pipe or culvert to sheet flow by causing the stormwater to spread out through a rock-lined trench before discharging over a berm, thereby dissipating energy that could cause erosion of downstream areas. The trench or channel is lined with filter fabric and covered with riprap, gabions, or a slope mattress to retard flow and provide turbulence. Energy is dissipated as stormwater spreads out over the rocks and then over the top of the berm. The berm is usually covered with riprap. Higher runoff velocities may be treated by placing gabions in the trench instead of riprap.

Level spreaders are located at the outlet of channels or culverts and are used to protect a receiving channel or downstream area from erosion by dissipating fluid energy. Level spreaders can be used to attenuate erosive flow velocities in stormwater discharges before they reach a vegetated BMP. They provide a moderate amount of coarse sediment removal and infiltration, but they are primarily a flow control device rather than a stormwater treatment system. A level spreader is shown in Figure 4-23.

Scope/Applicability

Level spreaders are used for moderate flows in small drainage areas. One of their primary applications is to convert channelized flows from culverts to sheet flows upstream of a vegetated filter strip or grassed swale. They should be constructed in undisturbed soils and discharge to stabilized areas.

Design Criteria Considerations

- Grass-lined trench used for flows up to 5 ft per second (ft/s).
- Riprap used for flows between 5 and 12 ft/s (median stone size of 8 inches, minimum thickness of 1 ft used for 5 to 8-ft/s flows; median stone size of 16 inches, minimum thickness 2 Et used for 8- to 12-ft/s flows).
- Riprap-lined channel not suitable for velocities greater than 12 ft/s or pipe diameters greater than 3 ft.
- Gabion rock mattress or slope mattress required to transmit flows of very high energy (between 12 and 20 ft/s).
- Adjust dimensions for varying pipe sizes, flows, and velocities.

Maintenance

Level spreaders require inspection and possible repair after large storms.

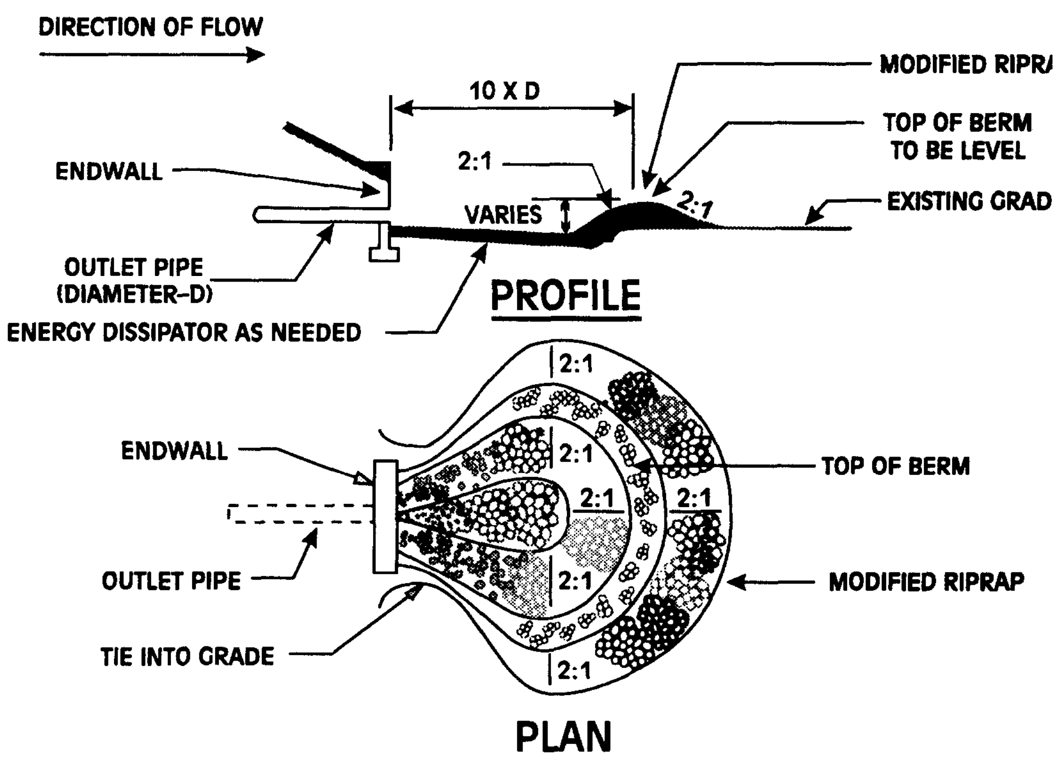
Potential Impacts to Wetlands

Benefits

- Reduction in the potential for adjacent wetland degradation resulting from erosion associated with peak stormwater flows.
- Possible reduction of stormwater sediment loads to adjacent wetlands.
- Possible reduction in the amount of stormwater-associated pollutants entering adjacent wetlands.

Limitations

- Primarily a flow control device and might not adequately improve the water quality of stormwater flows to adjacent wetlands.
- Might not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.



Adapted from Milone & MacBroom, Inc.. 1991.

Figure 4-23. Two views of a level spreader.

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Structural BMPs - French Drains

Definition/Purpose

A French drain is a type of exfiltration system that consists of a perforated pipe drain placed in a deep pit or trench that is filled with coarse open-grade rock. The trench is lined with filter fabric and can be extended out laterally from the roadway to increase its water holding capacity Water exfiltrates from the trench and into the surrounding soil. Dutch drains are similar to French drains except that water enters the Dutch drain through a cast iron grate at the trench surface instead of from a perforated pipe. Both French drains and Dutch drains are used to store runoff until it can percolate into the ground.

Scope/Applicability

French drains require permeable, well-drained soils. Soil permeability should be sufficient to provide a reasonable rate of infiltration, and the offset of the water table from the base of the trench facility should be enough to prevent pollution of the groundwater. Like other infiltration practices, installation of a catch basin ahead of the drain will help prevent clogging by coarse sediment and debris.

French drains are typically used in areas where space is restricted. They are normally used to catch runoff from parking lots, roadways, and roof drains. They are not recommended where runoff contains a high volume of suspended materials. Presettling, filtering, and oil and grease separators are recommended for use with French drains if high volumes of suspended materials are present in the runoff.

Design Criteria Considerations

- Location in suitable soils with infiltration rates of at least 0.5 inch per hour.
- Clearance of 6 to 10 inches between the trench bottom and the seasonal high groundwater level.
- Overflow pipe capable of handling at least a 25year storm event.
- Sediment traps located at least every 150 ft for a French drain.
- Complete drainage within 3 days after a storm to maintain aerobic conditions in the trench.
- Presettling or filtering of stormwater to remove coarse sediments.
- Sizing of the trench based on volume of runoff to be controlled.
- Use of observation wells to monitor performance.

Maintenance

Newly constructed French drains should be inspected quarterly after initial installation and after large rainstorms. The frequency of inspections may be decreased after the performance of the drain is verified, but inspections should be conducted on at least a yearly basis. Observation wells should be monitored to observe the functioning of the drain. If a filter strip precedes the drain, it should be inspected for patchy vegetation and erosion or signs of channelized flows.

Sediment that accumulates in the top foot of stone or at the inlet should be checked at the time of inspection and removed if infiltration rates have been reduced. Sediment that has collected in the sediment trap or pretreatment inlet should be removed periodically

Potential Impacts to Wetlands

Benefits

- Reduction in the amount of stormwater-associated pollutants entering adjacent wetlands.
- Reduction of stormwater sediment loads to adjacent wetlands.
- Reduction in the potential for adjacent wetland degradation resulting from erosion associated with peak stormwater flows.
- Potential recharge of groundwater from infiltration, benefiting adjacent baseflow-dependent wetlands.

Limitations

- Might not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.
- Possible reduction in the amount of surface water supplied to adjacent surface-flow-dependant wetlands as a result of rerouting.

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Structural BMPs - Dry Wells or Roof Downspout Systems

Definition/Purpose

Dry wells are infiltration pits used primarily to collect rooftop runoff from residential or commercial buildings, although they can be used to drain small parking lots. Dry wells may be constructed similar to infiltration trenches, using a filter fabric-lined pit filled with gravel, or they can consist of an underground perforated concrete tank lined with gravel. The interior of the perforated concrete structure can be filled with coarse gravel to provide structural stability Some dry well designs incorporate an outlet pipe leading to a drain field.

Dry wells can be used to reduce the amount of runoff collected at storm sewers and storm-water treatment facilities, especially when runoff from roofs is expected to be relatively clean. Dry wells increase infiltration and therefore help to recharge groundwater, provide base flow in streams, and reduce peak runoff volumes and stream bank erosion.

Scope/Applicability

Dry wells are suitable for use in areas where the subsoils are sufficiently permeable to provide reasonable infiltration rates and where there is sufficient offset to the groundwater. Their use is restricted to small sources of runoff such as from roof drains, small parking lots, and tennis courts. Roof downspout systems may be used to replace direct connections to sanitary sewers or storm sewers. They are adaptable to retrofitting in subdivisions because they are small, inexpensive, and relatively simple to install. Because dry wells provide minimal treatment of roof runoff, they should not be used in areas where air deposition of pollutants constitutes a major portion of the nonpoint source pollutant loads. A typical dry well/infiltratrion pit is shown in Figure 4-24. In areas where runoff contains high concentrations of suspended materials, a method of settling or pretreating runoff that filters out particles should be provided. Dry wells may be installed under pavement if they are equipped with a small yard drain or grate-covered catch basin to channel any overflow away from the overlying pavement.

Design Criteria Considerations

- Location in suitable soils having sufficient infiltration rates, preferably greater than 0.5 inch per hour.
- Water table offset of at least 3 ft from the bottom of the well.
- Detention time between 48 to 72 hours to allow for adequate pollutant removal.
- Complete drainage of well within 3 days to maintain aerobic conditions.
- Use of an observation well to monitor performance.
- Filter fabric wrapped completely around the aggregate rock.
- Length not to exceed 100 ft from the inlet sump.
- Line pits for precast concrete dry wells with a minimum of 1 ft of 0.75inch stone.
- Avoid placement under pavement whenever possible.
- Overflow drain for wells that are located beneath the pavement.

Maintenance

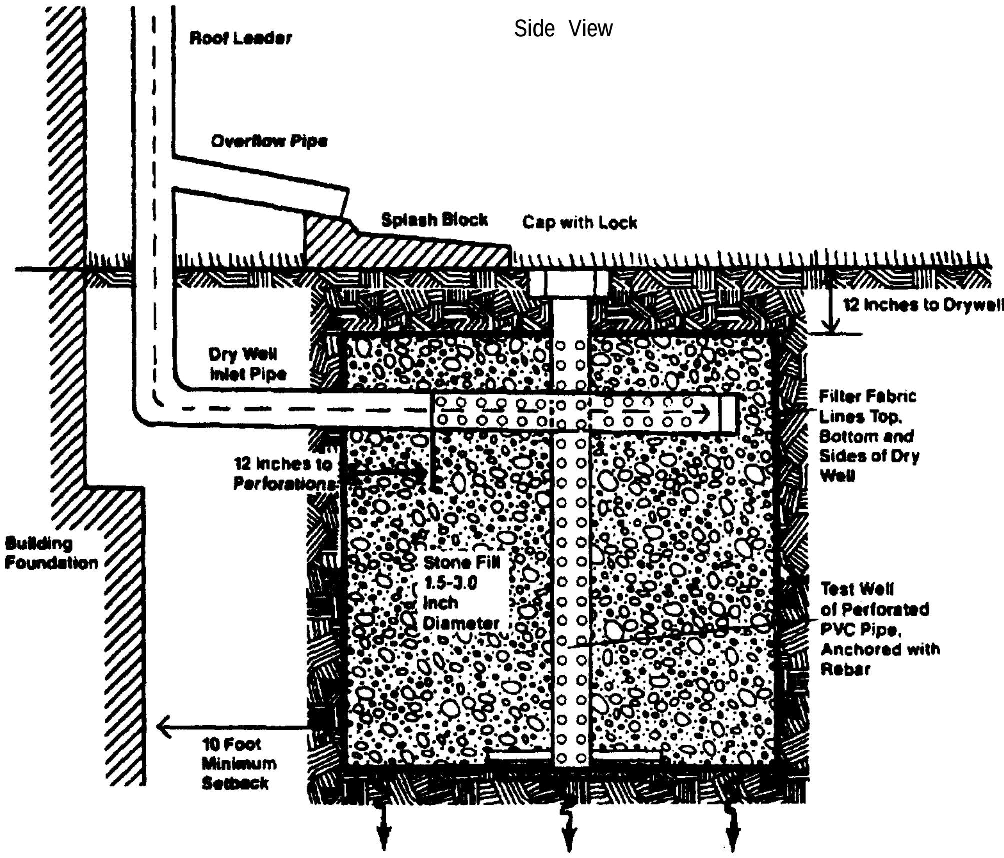
Dry wells and infiltration pits should be inspected frequently for proper drainage upon completion of construction and annually thereafter once performance of the device has been verified. Maintenance and inspection practices differ between dry wells and infiltration pits. Dry wells require periodic maintenance and inspection to prevent clogging and eventual failure. Filtering the stormwater through a fine mesh geotextile material will remove sediments and prevent premature clogging. The cap on a perforated concrete dry well can be removed for water level inspection and sediment removal. If the dry well becomes clogged, the rocks inside the concrete well will need to be removed. Sediments blocking the openings in the perforated lining should also be removed. After the rocks are removed, the well should be tested for drainage. If drainage rates are unsatisfactory, the precast concrete well might have to be removed. The pit itself might need to be enlarged if the soil adjacent to the well has become clogged. The dry well should then be rebuilt using clean rocks.

The maintenance of dry wells and infiltration pits is similar to that for an infiltration trench. An observation well installed in an infiltration pit will facilitate the inspection of water levels after storms. Frequent inspections are required during the rainy season. The accumulation of sediments in the top foot of stone aggregate or the surface inlet should also be monitored on the same schedule as the observation well to check for surface clogging. Clogging of the device is usually due to the accumulation of sediments between the upper layer of stone and the protective layer of filter fabric. When infiltrative capacity is significantly reduced, sediment should be removed from the top of the infiltration pit by removing the stone, replacing the filter fabric, and washing or replacing the stone.

Potential Impacts to Wetlands

Benefits

- Reduction in the potential for adjacent wetland degradation resulting from erosion associated with peak stormwater flows.



Adapted from Milone & MacBroom. Inc., 1991.

Figure 4-24. Dry well/infiltration pit.

- Possible reduction in sediment transport to adjacent wetlands resulting from reduced overland flow.
- Potential recharge of groundwater from infiltration, benefiting adjacent baseflow-dependent wetlands.

Limitations

- tight not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.
- Possible reduction in the amount of surface water supplied to adjacent surface-flow-dependent wetlands as a result of rerouting.
- May not adequately improve the water quality of stormwater flows to adjacent wetlands.

Sources of Additional Information

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Livingston, E., E. McCarron, C. Cox, and P Sanzone. 1993. *The Florida development manual: A guide to sound land and water management.* Stormwater/Nonpoint Source Management Section Florida Department of Environmental Regulation, Tallahassee, FL.

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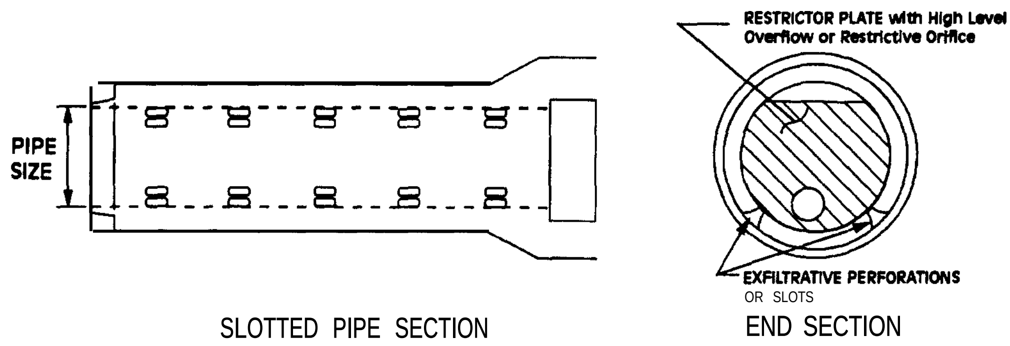
Structural BMPs - Exfiltration Trenches

Definition/Purpose

Exfiltration trenches are a series of underground slotted pipe sections that temporarily store stormwater while it exfiltrates into the underlying soil through perforations or slots in the pipe. A restrictor plate is placed at the end of the exfiltration pipe that controls the flow of water out of the pipe by using a high-level overflow device or a restrictive orifice. Exfiltration trenches require pretreatment of runoff to remove large particles of sediment and debris that may clog the pipes.

Scope/Applicability

Exfiltration trenches are used to provide groundwater recharge and a modest amount of temporary runoff storage. They are frequently used under parking lots to save space and have the advantage over infiltration basins of being hidden from sight. They can be used in situations where basins are visually unacceptable. Exfiltration trenches provide some reduction in peak flows especially if they are oversized to store runoff. Pollutants are filtered out as water passes through the soil under the system. Exfiltration trenches may be applied in moderately and well drained soils on low to moderate slopes. Two views of an exfilteration system are shown in Figure 4-25.



Adapted from Milone & MacBroom, Inc. **1991.**

Figure 4-25. Two views of an exfiltration system.

Design Criteria Considerations

- Two- to 4-ft offset from the pipe invert to groundwater.
- Two- to 4-ft offset to bedrock.
- Settle or filter runoff to remove solids.
- Level placement of pipes with no slope.
- Size for 0.5inch runoff minimum before overflow.
- Use in combination with a stone bed to increase storage capacity.

Maintenance

Exfiltration trenches require preventive maintenance to function effectively. Frequent cleanout of sediment traps and the maintenance or replacement of settling or filtering measures might be necessary If clogging of the facility occurs, replacement of the exfiltration trench might be required.

Potential Impacts to wetlands

Benefits

- Reduction in the amount of stormwater-associated pollutants entering adjacent wetlands.
- Reduction of stormwater sediment loads to adjacent wetlands.
- Reduction in the potential for adjacent wetland degradation resulting from erosion associated with peak stormwater flows.
- Potential recharge of groundwater from infiltration, benefiting adjacent baseflow dependent wetlands.

Limitations

- Might not adequately attenuate concentrated peak stormwater flows to adjacent wetlands.
- Possible reduction in the amount of surface water supplied to adjacent surface-flow-dependent wetlands as a result of rerouting.

Sources of Additional Information

Livingston, E., E. McCarron, C. Cox, and P. Sanzone. 1993. *The Florida development manual: A guide to sound land and water management*. Stormwater/Nonpoint Source Management Section Florida Department of Environmental Regulation, Tallahassee, FL.

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BMPs in Series

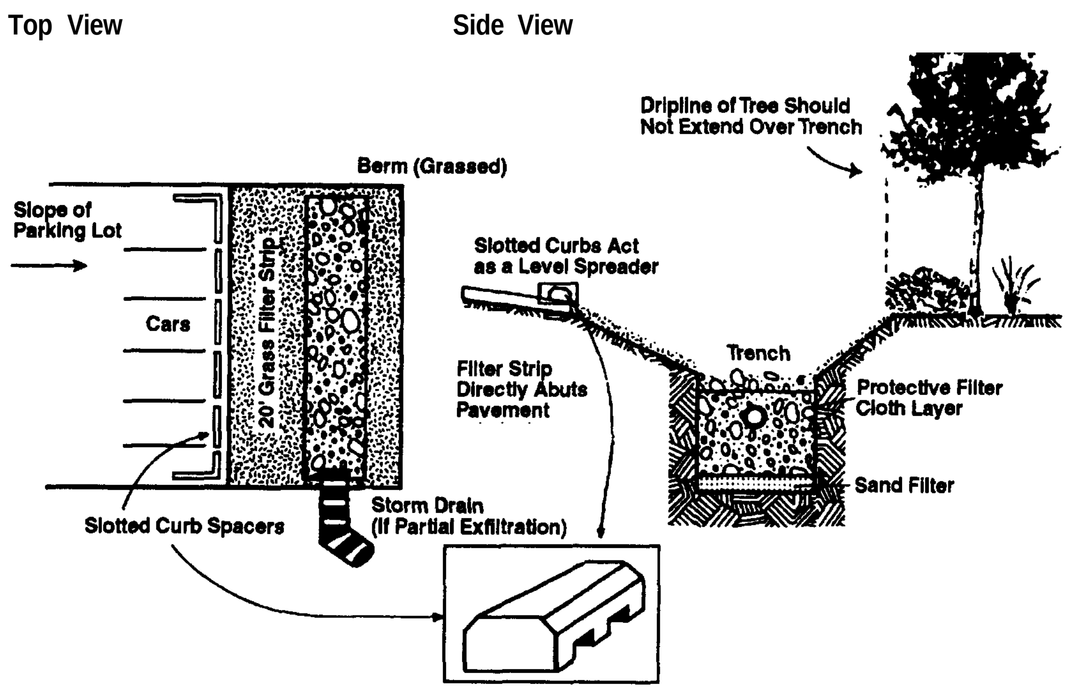
Definition/Purpose

BMPs in series incorporate several stormwater treatment mechanisms in a sequence to enhance the treatment of runoff. Some examples of serial BMPs include the use of multiple pond systems, the combination of vegetated filter strips withgrassed swales and detention ponds, and the combination of grassed swales or vegetated filter strips with infiltration trenches.

By combining structural and/or nonstructural treatment mechanisms in series rather than using a single method of treatment for stormwater runoff, the levels and reliability of pollutant removal can be improved. By using serial BMPs, a single desired facility that might not provide the necessary level of stormwater treatment without sequencing can be used. The effective lifetime of a BMP can be increased by combining it with a pretreatment device, such as a grassed swale, to remove suspended particulates prior to treatment in the downstream unit. Sequencing of BMPs can also reduce the potential for resuspension of deposited sediments by reducing flow energy levels or by providing longer flow paths for runoff. An example of using BMPs in series is shown in Figure 4-26.

Scope/Applicability

The feasibility of using serial BMPs on a site depends on the characteristics of the individual components in the sequence.



Adapted from Schueler, 1991.

Figure 4-26. *Example of BMPs in series.*

Design Criteria Considerations

Design criteria considerations depend on the requirements of the individual BMPs. The least expensive and most easily maintained component should be placed at the most upstream position in the series.

Maintenance Requirements

The maintenance requirements for serial BMPs depend on the requirements of the individual components of the system. (Refer to the individual BMP fact sheets.) A firmly established maintenance and inspection program that addresses both routine and nonroutine tasks is necessary to ensure that the system functions as designed.

The placement of the least costly and most easily maintained BMP at the most upstream position in the series can reduce the maintenance requirements for the downstream components in the system. If the overall system is designed properly, the cost for maintenance of the individual components of the system can be reduced.

Potential Impacts to Wetlands

The potential impacts resulting from the placement of serial BMPs above, adjacent to, or within wetlands will depend on the components of the system. The potential positive or negative impacts of the individual components should be considered. The potential impacts of the individual components of the serial BMP should then be evaluated as a whole to determine their possible impact to adjacent or downstream wetlands.

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