

SECTION II: WATER QUALITY PROTECTION TECHNIQUES

WATERSHEDS AND WATER QUALITY

A. Impacts on Water Quality

Water quality is a product of the watershed. Land-based activities significantly determine the quality of Long Island Sound. Urbanization, therefore, has a significant influence on water quality. By comparing a stream or wetland in a developed area to one in a more natural setting, detrimental impacts of nonpoint source pollution can be more easily identified. Specifically, the typical urban stream and wetland exhibits a lesser density and diversity of microbic life forms; aquatic organisms in these water resources are typically associated with environments stressed by hydrologic changes and point and nonpoint source pollution. Detrimental impacts associated with development include massive "pulses" of sediment during construction, increased wash-off of pollutants (trash and debris, trace metals, nutrients, toxics, hydrocarbons), increased stream temperatures, and nutrient enrichment and subsequent algal growth. Nutrients and pollutants may be dissolved in water or may adsorb (attach) to sediment particles. These particles may then wash downstream where they can accumulate in depositional areas or be released into other water resources. The net effect of urbanization often is an increase in pollutant export by at least one order of magnitude over pre-development levels. This impact is not only seen in streams or wetlands, but is felt by downstream receiving waters such as lakes, rivers and estuaries. Results of the Long Island Sound Study conclude that the water quality of Long Island Sound exhibits the symptoms of urban stress.

Urbanization reduces the amount of stormwater that is absorbed by the ground, thereby increasing stormwater runoff volume. The vast parking lots, buildings, roads and other impervious surfaces associated with urban areas result in large amounts of stormwater runoff, resulting not only in less water infiltration but also less available water to recharge ground and surface waters. Urban stormwater runoff also transports pollutants (nonpoint source pollution) from land surfaces to water resources, such as wetlands, streams and lakes.

In addition to nutrients and toxicants that are generated from existing residential and commercial land use, there are numerous other nonpoint pollution sources which need additional attention, including construction site erosion, and runoff from waste disposal sites and resource extraction industries, such as mining and sand and gravel operations. These sources cumulatively have a tremendous effect on the water quality of streams, freshwater water bodies, wetlands and, ultimately, Long Island Sound. The most prevalent types of nonpoint pollution are discussed below.

B. Types of Nonpoint Source Pollutants

The major urban nonpoint sources of pollution in the Long Island Sound watershed are sediment, excess nutrients, bacteria, hydrocarbons (petroleum), trace metals, chemicals, chlorides, and thermal impacts. The following is a description of the water resource impacts of each of the primary nonpoint source pollutants.

Sediment

Sediment adversely impacts water resources in many ways. Suspended sediment in streams causes increased turbidity, transport of excess nutrients and pollutants to the water column, reduced light penetration, reduced prey capture for sight feeding predators, clogging of gills/filters of fish and aquatic invertebrates, reduced spawning and juvenile fish survival, and reduced angling success. Additional impacts result after sediment is deposited in the slower moving "receiving" waters. These impacts include the smothering of aquatic organisms living on the bottoms of streams, ponds and estuaries, changes to the composition of stream and water body bottoms, speedier filling of small impoundments which creates the need for costly dredging, and reduction in aesthetic values. Sediment also can be an efficient carrier of toxic substances and trace metals. Pollutants in these enriched sediments can be remobilized under suitable environmental conditions, posing a risk to aquatic and other life.

The greatest sediment loads are exported during the construction phase of development sites. In dense urban areas, sediment discharged to streams and lakes from developed sites generates between 10,000 to 100,000 tons/square mile/year of sediment. This is an average estimate of erosion. The amount of sediment reaching a water body from a particular site is highly variable and is very dependent on factors such as size of disturbed areas, proximity to waterways, soil type, and slope. In any construction activity, proper measures can be taken to reduce nonpoint source pollution and the consequent deleterious effects on water quality.

Nutrients

Excess levels of phosphorus and nitrogen in urban runoff can lead to undesirable algal blooms in downstream receiving waters. Excessive algae and aquatic plant growth (except for eelgrass beds, which tend to decline during eutrophication) can choke open waters and consume oxygen, mainly through plant die-off. Fish and aquatic organisms, recreational values, and the use of the resource for water supply are thereby impacted. Bioassays have indicated that the typical nutrient concentrations in urban runoff are more than sufficient to stimulate excessive algal growth; a majority of the nutrients in urban runoff are present in soluble forms which are readily taken up by algae. Thus, any additional nutrient load from nonpoint source pollution will only increase degradation of the system.

Aside from promoting growth of dense mats of algae, nutrients can enhance eutrophic processes in urban lakes, detention basins and other fresh and tidal waters. These systems will show evidence of surface algal scums, water discoloration, strong odors, depressed oxygen levels, release of toxins, and reduced palatability. Nitrogen contamination of drinking water significantly above the drinking water standard may also cause methoglobinemia ("blue-baby" syndrome) in infants and has forced closure of several water supplies (primarily wells). As a general rule, nutrient export is greatest from development sites with sizable impervious areas and managed landscape components, such as lawns.

Bacteria

Bacteria (and viruses) include infectious agents and disease producing organisms normally associated with human and animal wastes. The principal concern is the survival and transmission of such organisms and their impacts on drinking water supplies, contact recreational waters, and fish and wildlife or domestic animals. Bacteria multiply faster during warm weather. A twenty-fold increase in bacterial levels may occur from winter to summer.

Older and more intensively developed urban areas produce the greatest bacterial export. The problem is especially significant in urban areas which experience sewer overflows and septic system failures, which export bacteria in untreated or partially treated human wastes. In surface water, bacterial survival is

dependent on temperature and salinity, but few species can live in brackish water. Coliform bacteria tend to be common, and may indicate sewage pollution if they are of the fecal coliform group.

Oxygen Demand

Decomposition of organic matter, both natural (such as sewage and algae) or synthetic (such as PCBs, pesticides and herbicides) depletes dissolved oxygen (DO) levels in receiving waters such as lakes and estuaries. Natural decomposition of these materials may deplete dissolved oxygen levels in bottom waters. As a result, DO levels may be reduced below the threshold necessary to maintain aquatic life, impairing or killing slower-moving fish and other aquatic biota, especially shellfish and crustaceans. DO depletion is measured by examining the amount of easily oxidized organic matter present in water.

Oil and Grease

Hydrocarbons (oils and other petroleum compounds) are known to be toxic to aquatic life at relatively low concentrations. Hydrocarbons are lighter than water and are initially found in the form of a rainbow colored film on the water's surface. Hydrocarbons tend to have a strong affinity for sediment, and much of the hydrocarbon load eventually adsorbs to particles and settles out. If not trapped by control measures, hydrocarbons tend to rapidly accumulate in the bottom sediments of lakes and estuaries where they may persist for long periods of time, and have long-term adverse impacts on fish, wildlife and microorganisms, habitat and public water supply sources.

The major source of hydrocarbons in urban runoff is through leakage of crankcase oil and other lubricating agents from automobiles. As might be expected, hydrocarbon levels are highest in the runoff from parking lots, roads and service stations. Residential land uses generate less hydrocarbon export, although illegal disposal of waste oil into storm sewers can be a local problem.

Trace Metals

Trace metals are primarily a concern because of their toxic effects on aquatic life, and their potential to contaminate drinking water supplies. Significant amounts of trace metals become attached, or adsorbed, to sediment, which then may transport the trace metals to other water resources or other areas of the same resource if the sediment becomes suspended in the water column of streams and rivers. Metals can be discharged to surface water and groundwater from a variety of sources including industrial plating operations, waste oil discharges, and pesticides.

Toxic Chemicals

Toxic chemicals may enter surface waters either in dissolved form in runoff or attached to sediment and organic materials and may enter ground water through soil infiltration. The principal concerns in surface waters are their entry into the food chain, bioaccumulation, toxic effects on fish, wildlife and microorganisms, habitat degradation, and potential degradation of public water supply sources. The ground water impacts are primarily related to water supply sources.

Chlorides

Chlorides, or salts, often wash off into streams after they are applied to remove ice and snow from roads, driveways, parking lots and sidewalks. Salt levels in snowmelt runoff have been reported to exceed several thousand milligrams per liter, which can be dangerously high for some water resources. Due to its extreme solubility, almost all chloride applied for snow removal purposes ends up in stormwater

runoff. At high levels, chlorides are toxic to many freshwater aquatic organisms which can withstand only relatively low salinity.

Thermal Impacts

Elevated water temperatures can have detrimental impacts on water quality. Elevated stream temperatures can exceed fish tolerance limits, reducing survival and lowering disease resistance. A rise in water temperature of just a few degrees over ambient conditions can reduce or eliminate sensitive stream insects and fish species, such as stoneflies, mayflies and trout. In general, sustained summertime water temperatures in excess of 70 degrees Fahrenheit are considered to be stressful, if not lethal, to many cold water organisms.

A number of factors can increase summertime water temperatures in urban headwater streams. Of these, three factors often act synergistically to increase water temperatures. First, as the urban landscape heats up on warm summer days, it tends to impart a great deal of heat to any runoff passing over impervious surfaces, such as parking lots. Second, few trees may exist on streambanks to shade stream channels. Third, runoff stored in shallow wet ponds and other impoundments may be heated between storms, and then may be released in a rapid pulse during and shortly after storms.

C. Best Management Practices

Reducing, restoring and preventing the impacts of nonpoint source pollution can be accomplished in part by using best management practices (BMPs). Numerous BMPs have been developed to decrease soil loss and the transport of nutrients and other contaminants. Effectiveness in preventing nutrient export, technical feasibility, social acceptability and cost vary widely among the practices. Some practices are more suitable for new developments than for developed areas. Although BMPs seldom provide a complete solution in restoring natural resources and water quality, they are key elements in an evolving strategy that recognizes that natural resources can be managed and protected only in the context of the watershed in which they exist. BMPs are defined as the most effective practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.

BMPs consist of a wide range of pollution prevention techniques. They range from structural practices, such as detention basins, to non-structural techniques, such as pollution prevention programs and regulatory controls. Nonstructural BMPs seek to prevent contamination of runoff through planning, design, maintenance, and education. They are a proven, cost-effective way to manage urban runoff. Nonstructural BMPs focus on pollution prevention, information and education, and regulatory controls which reduce nonpoint source pollution. Implementing nonstructural BMPs requires cooperation and participation from municipal personnel, project proponents, and the public.

Structural BMPs are structures specifically designed and constructed for the reduction of nonpoint source pollution. There are a variety of structural BMPs, both vegetated and nonvegetated. Vegetative structural BMPs range from filter strips and grassed swales to artificial wetlands. Non-vegetative practices can consist of bank stabilization structures, stormwater detention basins, water quality inlets and oil and grease catch basins. A combination of vegetated and non-vegetated structures can also be used.

The following is a list of various nonstructural and structural BMPs which can be used to reduce nonpoint source pollution. Table 3 provides a comparative assessment of the effectiveness of the most widely used management practices listed below.

- Infiltration Practices

- /Dry Detention Basins
- Streambank Stabilization Structures
- Grassed Swales
- Filter Strips
- Filter Fences and Other Construction Site Erosion Controls
- Education
- Land Use Planning/Zoning
- Construction Erosion Control
- Comprehensive Site Planning
- Sanitary Waste Management
- Buffer Zones
- Setback Requirements
- Easements
- Catch Basin Cleaning
- Alternative Salting Methods
- Street Sweeping
- Combined and Separate Storm Sewer Systems
- Petroleum Storage Tank Regulations
- Spill Prevention Programs
- Animal Waste Collection
- Proper Pesticide and Fertilizer Use and Application
- Neighborhood Recycling Program

Table 3. A comparative assessment of the effectiveness of current urban best management practices							
URBAN BMP OPTIONS *	RELIABILITY FOR POLLUTANT REMOVAL.	LONGEVITY*	APPLICABLE TO MOST DEVELOPMENTS	WILDLIFE HABITAT POTENTIAL.	ENVIRONMENTAL CONCERNS	COMPARATIVE COST	SPECIAL CONSIDERATIONS
STORMWATER WETLANDS	Moderate to high, depending on design	20+ years	Applicable to most sites if land is available	High	Stream warming; natural wetland alteration	Marginally higher than wet ponds	Recommended with design improvements and the use of micropools and wetlands
EXTENDED DETENTION PONDS	Moderate, but not always reliable	20+ years, but frequent clogging and short detention common	Widely applicable, but requires at least 10 acres of drainage area	Moderate	Possible stream warming and habitat destruction	Lowest cost alternative to size range	Recommended with design improvements and the use of micropools and wetlands
WET PONDS	Moderate to high	20+ years	Widely applicable, but requires drainage area of greater than 2 acres	Moderate to high	Possible stream warming, trophic shifts, habitat	Moderate to high compared to conventional	Recommended, with careful site evaluation
MULTIPLE POND SYSTEMS	Moderate to high; redundancy in-creases reliability	20+ years	Widely applicable	Moderate to high	Selection of appropriate pond option minimized overall environmental impact	Most expensive pond option	Recommended
INFILTRATION TRENCHES	Presumed moderate	50% failure rate within five years	Highly restricted (soils, groundwater, slope, area, sediment input)	Low	Slight risk of groundwater contamination	Cost-effective on smaller sites; rehab costs can be considerable	Recommended with pretreatment and geotechnical evaluation
INFILTRATION BASINS	Presumed moderate if working	60-100% failure within 5 years	highly restricted (see infiltration trench)	Low to moderate	Slight risk of groundwater contamination	Construction cost moderate, but rehab cost high	Not widely recommended until longevity is improved
POROUS PAVEMENT	high (if working)	75% failure within 5 years	Extremely restricted (traffic, soils, groundwater, slope, area, sediment input)	Low	Possible groundwater contamination	Cost-effective compared to conventional asphalt when working properly	Recommended in highly restricted applications with careful construction and effective maintenance
SAND FILTERS	Moderate to high	20+ years	Applicable for smaller developments	Low	Minor	Comparatively high construction costs and frequent maintenance	Recommended, with local demonstration
GRASSED SWALES	Low to moderate, but unreliable	20+ years	Low density development and roads	Low	Minor	Low compared to curb and gutter	Recommended, with checkdams as one element of a BMP system
FILTER STRIPS	Unreliable in urban settings	Unknown, but may be limited	Restricted to low-density areas	Moderate if forested	Minor	Low	Recommended as one element of a BMP system
WATER QUALITY INLETS	Presumed low	20+ years	Small, highly impervious catchments (<2 acres)	Low	Resuspension of hydrocarbon loadings; disposal of hydrocarbon and toxic residuals	High, compared to trenches and sand filters	Not currently recommended as a primary BMP option

* Based on current designs and prevailing maintenance practices. *Source: Metropolitan Washington Council of Governments /991.*

MUNICIPAL REGULATORY AND NON-REGULATORY TOOLS

Health regulations, zoning ordinances, land acquisition and voluntary controls are some of the options available to local governments in their mission to manage the water resources that protect the public health, safety and welfare. Health regulations can address both proposed and existing development and their impacts on water quality. Zoning controls are limited in that they are prospective--they typically apply only to future development and not to existing activities which are exempt or "grandfathered." General police powers are available under a community's home rule powers to protect the public health, safety, and general welfare. Non-regulatory options may include educational efforts, monitoring, the adoption of certain best management practices, and land acquisition.

The type of control that a community may consider also will help determine who should be involved in the local community. For example, if boat sanitary waste dumping is considered a threat, the local harbormaster should be involved in drafting regulatory measures. It also would be valuable to gather support from local marinas that may be affected by new mooring and pump-out regulations.

Many of the tools listed in this chapter are designed for protection of groundwater, focusing on preventative action for coastal waters because polluted groundwater can be a significant source of contamination in surface waters. For both surface and ground waters, pollution prevention is much cheaper than clean up after the fact.

A. Regulatory Tools

Zoning Regulations

Zoning techniques offer another powerful tool to protect water quality. These are often overlooked. The use of floor area ratios (FAR), and maximum building and lot coverages limit the conversion of land to impervious surfaces (lot coverage differs from building coverage because it includes all impervious surfaces, such as paved areas, in addition to buildings). This allows for greater infiltration of stormwater and minimizes the potential for pollutant-carrying runoff. These criteria could be enhanced by excluding land areas unsuitable for building, such as wetlands, steep slopes, etc.

All municipalities in WAC 5 have building coverage limits. New Rochelle, Mamaroneck Town and Mamaroneck Village also employ FAR limitations for certain developments. Only New Rochelle has lot coverage specifications. While New Rochelle excludes underwater lands from its calculations, none of the other municipalities factor in site characteristics when determining total lot area in coverage calculations.

Zoning regulations have been used throughout the country, in coastal and inland areas, to segregate different and possibly conflicting activities into different areas of a community. The following are important zoning techniques that can be used to protect coastal resources.

Overlay Water Resource Protection Districts

One technique designed to update zoning regulations for protection of a surface or groundwater resource is the creation and adoption of overlay water resource protection districts by law. The law, which may vary by municipality in its approach toward resource protection (i.e., prohibition of various uses versus special permitting and/or performance criteria), defines the resource by mapping watershed boundaries and enacting specific legislation for land uses and development within these boundaries.

Watershed Zoning

A new zoning technique that has been instituted in a few communities (but not yet tested extensively) is watershed zoning. This is simply the idea of extending zoning districts onto water bodies. Under traditional zoning, specific areas of a community are set aside for various land uses. Under zoning, certain areas of the water body are set aside for such water-dependent uses as navigation channels, mooring areas, water-skiing, and so on.

Prohibition of Various Land Uses

Virtually every community that has adopted zoning prohibits certain land uses from specific sections of the community, although the rationale behind such prohibition may or may not be related to water resource protection. While not the most creative nor effective approach toward resource protection, prohibition of land uses such as gas stations, sewage treatment plants, landfills, or others involving the use, storage and disposal of toxic and/or hazardous materials is a first step toward the development of a comprehensive water resource protection strategy.

Special Permitting

If applied strictly, the special permitting process can be used effectively to regulate uses and structures that may potentially degrade water quality. For example, many communities use the special permitting process to regulate underground storage tanks or limit lawn fertilizer use within critical areas.

Large Lot Zoning

Large lot zoning, as the title implies, seeks to limit water resource degradation by reducing the number of buildings and, therefore, septic systems within a protection area. Large lot zoning is sometimes difficult to enact depending on circumstances, such as existing zoning and growth characteristics. Nevertheless, when used as part of an overall protection strategy, large lot zoning within resource-contributing areas can be an effective tool against water contamination. There is no definition of "large lot" zoning, although case law has upheld different variations on local government's use of minimum lot size.

Transfer of Development Rights

The idea of "transfer of development rights" (TDR) is based on the concept that a parcel of land has a bundle of different "rights" associated with it. A TDR program allows a landowner to separate his or her right to develop the land, as permitted by zoning, from the other rights associated with the land, and sell those development rights.

To implement a TDR program, a governmental entity such as the town would prepare a plan designating the parcels or districts from which development rights could be transferred (a "sending"

or "donor" parcel), and the parcels or districts which would receive those development rights and be developed at a higher density than allowed by the underlying zoning district (a "receiving parcel").

Typically, a sending parcel or district might be within a contributing area to an estuary or other water resource. A receiving parcel is able, both from a physical standpoint and in terms of the community's growth program, to accommodate additional development beyond that allowed as-of-right by zoning. In selling his or her development rights, a landowner would gain the cash value of whatever development rights the market associates with the land, and yet would keep the land in a less intensive use and help protect the resource in question. A perpetual easement or some other development restriction would be recorded with the deed of the sending or donor parcel. The purchaser of the development rights gains the ability to develop the receiving parcel at a higher density than allowed "as-of-right" and can recapture the cost of the purchased development rights through the more intensive use of the receiving parcel.

Cluster Development

Cluster zoning is an alternative to the standard grid-style subdivision. It allows buildings to be "clustered" more densely on a portion of the site most suitable for development, in exchange for preserving the rest of the site, including any sensitive coastal areas, as contiguous open space. In a cluster development, smaller building lots are allowed, with resulting land savings set aside in contiguous areas of open space.

Subdivision or zoning regulations should contain provisions that enable a developer to modify minimum lot size and other dimensional requirements as part of the subdivision approval process. This "clustering" technique allows for a grouping of dwelling units on one or more portions of the site with the remainder set aside as common open space. This process encourages diversity in housing design, preserves open space and allows development to account for variations in the natural environment. Clustering also is a way for developers to minimize expenses for development, with shorter sewer and utility lines and a smaller road system. Clustering provides tremendous flexibility for both the developer and municipality, and often allows for greater creativity in the division of large land parcels.

Growth Controls/Timing

Growth controls are techniques that are used to slow or guide a community's growth, ideally in concert with its ability to "support" growth. The term "support" has been broadly defined, and can include issues ranging from a city or town's physical and financial ability to provide public facilities (roads, water, sewer, schools and public safety) to its ability to retain its once rural, historic character. Growth controls vary in their application and have included outright moratoria to limitations on numbers of building permits issued in any twelve month period. One of the most widely referenced examples of growth control is the 1969 Ramapo, New York ordinance that limited growth and development in the community to a rate commensurate with the town's ability to provide services to new (and existing) residents.

Falmouth, Massachusetts used growth controls to limit land subdivision within the rapidly developing watersheds to its coastal ponds. In 1985, the town adopted a subdivision phasing regulation designed to slow development within these sensitive resource areas. The idea was to "buy time" for the town to implement other management controls such as rezoning, land acquisition and monitoring to protect the coastal water resources.

Performance Standards

Performance standards are based on the assumption that any given resource has a threshold, beyond which the resource's ability to function deteriorates to unacceptable levels. Performance controls assume that most uses are allowable within a designated area provided that the uses do not and will not overload the resources. A good example of a performance standard is one designed to protect surface water quality by setting a critical threshold for contaminants. Those land uses which will cause the threshold to be exceeded in the water body are not allowed.

Approximately one year before Falmouth, Massachusetts adopted the growth controls noted above, the town instituted a unique and precedent-setting approach to manage development in watersheds to the town's coastal resources. All development within defined, mapped areas (mapped as an overlay zoning district) was required to adhere to strict performance standards. In effect, these standards were designed to ensure that all development within watersheds to coastal ponds, when analyzed cumulatively, would not exceed the assimilative capacity of the resources.

Health Regulations

The development of health regulations is an extremely effective method of rounding out a community's regulatory protection program. The following are examples of well-accepted techniques using health regulations to protect coastal and water resources.

Underground Storage Tanks

Leaking underground storage tanks may be the single largest source of groundwater contamination in the nation. The larger underground gasoline storage tanks associated with automotive service stations have caused numerous groundwater contamination incidents. As noted earlier, if compounds from these tanks enter estuaries, they may be accumulated by shellfish, presenting a health risk to consumers.

Potential components of tank regulations are: leak testing and construction standards for new, large tanks such as those at automotive service stations; prohibition of new residential underground storage tanks if they cannot be adequately monitored; removal of existing residential underground storage tanks; and prohibition of all new underground tank installation (except for replacements) within watersheds.

Privately-Owned Small Sewage Treatment Plants

Privately-owned small sewage treatment plants (SSTPs) have been utilized as a technological solution to prevent overloading of the natural capabilities of land and associated water resources to assimilate wastewater discharges. The use of these small treatment plants has, in some cases, allowed development of land beyond the development that would be possible using conventional, individual septic systems.

The effectiveness of SSTPs is dependent upon the proper functioning of more components than that associated with a standard septic system. SSTPs also require supervised operation and maintenance. Consequently, they are more likely to malfunction and their use may be a risk in critical resource areas. To eliminate these risks in critical water resource areas, some communities have entirely banned the use of SSTPs.

Septic System Maintenance

The maintenance of on-site septic systems is frequently overlooked. The result is typically an overloading of solids moving to the leaching facility and subsequent clogging. When this occurs, the system needs to be rehabilitated. This is commonly done with the use of strong acids or organic solvents. However, these chemicals are contaminants and can degrade ground and surface water quality. To minimize this danger and to ensure proper maintenance of septic systems, many communities have developed a voluntary septic system maintenance program. The key component of such a program is pumping every two to three years for residential septic systems.

Boat Pump-Out Facilities and Head Use Limitations

Since near-shore dumping of human wastes from boats can cause contamination of shellfish beds and swimming areas as well as nutrient enrichment, some communities have enacted limitations on dumping and taken action to provide pump-out facilities. For example, Kent County, Maryland requires all new or expanding marinas to install pump-out facilities and to provide signs notifying boaters of the facility. In Prince William County, Virginia, the county supplements state requirements to ensure that at least one pump-out facility is available on any tidal creek with a marina.

Subdivision Rules and Regulations

Subdivision regulations fine-tune zoning ordinances in that they focus less on land use and more on engineering concerns, such as road construction, utilities and site plan layout of individual subdivisions. Protecting coastal water resources via subdivision control is, therefore, less effective than via zoning, but can still be used to ensure that drainage and landscaping designs fit with the goal of resource protection. Following are some important techniques to consider.

Stormwater Management

A key component of nonpoint source pollution is stormwater runoff (see Chapter ---- for additional information). As lands become developed and more urbanized, less precipitation reaches the earth where it can be absorbed and naturally filtered. In addition to flooding and stream channel erosion, the increased runoff carries with it pollutants from developed areas, which accumulates and finally discharges into natural waterways. While many municipalities recognize the importance of controlling water quantity to prevent downstream flooding, few municipal regulations actually provide volume standards; fewer still provide standards to protect stormwater runoff water quality. The usual approach of extrapolating stormwater management authority from existing ordinances, such as subdivision, zoning or flood controls, was found inadequate for two reasons: (1) ordinances for other purposes are not easily adapted and (2) enforcement is difficult because courts have been reluctant to rule in favor of ambiguous regulatory authority and against well-established private property rights. This strongly suggests the need for specific local stormwater management ordinances.

As understanding of pollutant contributions from runoff grows, guidelines are developed to effectively treat runoff for water quality. These include:

- NYSDEC SPDES General Permit for Stormwater Discharges from Construction Activities (Effective August 1, 1993-1998)
- NYSDEC Division of Water Technical and Operational Guidance Series 5.1.8: Stormwater Management Guidelines for New Development (1990)

- NYSDEC Reducing the Impacts of Stormwater Runoff from New Development (1992)
- Westchester County Best Management Practices Manual for Stormwater Runoff Control (1984)

Guidelines recommend the capture and treatment of the "first flush" (the first half inch of runoff) from impervious surfaces. It also identifies the order, or hierarchy, in which a control measure are selected; infiltration is most preferred, then retention and, lastly, extended detention (refer to stormwater section for complete discussion).

Currently, only Mamaroneck Town has developed a special ordinance covering stormwater management. Mamaroneck Village, Larchmont, and New Rochelle contain references to stormwater management in other existing ordinances, such as subdivisions and building regulations, but they are very generalized, focus mainly on quantity, and do not provide the specificity needed to ensure consistent implementation of effective control measures. All municipalities have adopted Floodplain Damage Prevention ordinances, but these are based on Federal Emergency Management Agency (FEMA) requirements for flood insurance and refer generally to the prevention of downstream flooding so as to minimize life endangerment and property damage. Though already densely developed, the villages of Pelham and Pelham Manor could benefit from standards that might be incorporated into existing ordinances or combined under new regulations as recommended herein.

Drainage Requirements

Overland runoff from subdivisions often contributes nutrients, metals, and other contaminants to surface waters. To help control this problem, drainage requirements may be established by local planning commissions and boards as part of subdivision review processes. (Drainage best management practices are also effective in non-subdivision areas.) The table below shows costs and benefits for seven drainage management options:

<i>Comparative Costs of Stormwater Management Techniques</i>			
Technique	Construction Costs	Maintenance Costs	Water Quality Benefits
Grassed swale	Low	Moderate	Moderate
Infiltration basin	Moderate-high	High	Moderate-high
Infiltration trench	Low-moderate	Moderate-high	Moderate
Porous pavement	High	High	Moderate
Detention pond	Low-moderate	Moderate-high	Moderate-high
Retention pond	High	Moderate-high	High
Constructed wetland	High	Low	High

Effective drainage management should minimize the volume of runoff generated as well as enhance filtration. Steepness of constructed slopes should be minimized, and bare surfaces revegetated as quickly as possible.

Environmental Impact Assessments

Proposed subdivisions which exceed a certain number of proposed lots may be required to prepare environmental impact assessments or statements. These environmental analyses may require varied information depending on community needs and water resource protection goals. Possible requirements are: identification of sensitive water receptors downgradient on- and off-site; information on the existing condition of these resources; and potential impacts from the proposed development on coastal areas or other nearby sensitive areas.

Performance Standards

Subdivisions may be regulated on the degree of impact the full development could have on water resources. Performance standards, such as nitrogen and phosphorus loading limitations, may thus be specified to keep contamination from the subdivision below assimilation capacity of the downgradient water resource. The developer can be required to determine impacts, perhaps through the EIA process (above).

Site Design/Landscaping

Water quality protection may be enhanced via requirements for vegetated buffer zones, natural landscaping in key areas, and the reduction of impervious areas through stringent coverage standards and alternative roadway designs. In establishing landscaping requirements, communities should encourage xeriscaping techniques under appropriate conditions. Xeriscaping focuses on the use of native plant materials having lower water and nutrient requirements than standard landscape species. Use of highly demanding exotics should be discouraged.

Steep Slopes

Sloping topography typically has greater potential to erode. This has led some municipalities to create special ordinances regulating development on steep slopes. While the definition of steep slopes can vary, slopes of 15 percent (that is, a 1.5 foot vertical rise for every foot of horizontal run) or greater have been identified as the threshold for special controls.

In WAC 5, there are relatively few areas with steep slopes. According to the County's Environmental Planning Atlas, which is based on U.S.G.S. topographic maps, Larchmont and Pelham Manor have no slopes of 15 percent or more. New Rochelle, Pelham, and Mamaroneck Town and Village show some slopes of greater than 15 percent; however, many of these areas are either already developed or are preserved as open space. Consequently, none of the municipalities in WAC 5 have or need a steep slopes ordinance. Additional controls should be incorporated in erosion and sediment control ordinances, such as that for the Town of Mamaroneck, to protect the remaining potentially vulnerable areas.

Wetland Regulations

It is a well-documented fact that wetlands are a critical component in the protection of both surface and groundwater quality. Wetlands absorb and contain floodwaters and have been shown to remove significant quantities of pollutants through a combination of physical, chemical and biological processes.

The necessity of local ordinances is clearly evident. There are both federal and state laws that regulate impacts to freshwater wetlands. However, under the New York State Freshwater Wetlands Act (Article 24 of the Environmental Conservation Law), regulated wetlands are generally limited to those which are 12.4 acres or larger in size. In the WAC 5 study area, there is only one such state wetland. The U.S. Army Corps of Engineers (ACOE) regulates disturbance to virtually any wetland or water body under Section 404 of the Clean Water Act.

Tidal wetlands also are both federally and state regulated. The ACOE regulates tidal wetlands under Section 404 as well. The State regulates tidal wetlands under the Tidal Wetlands Act (Article 25 of the Environmental Conservation Law) and its implementing regulations 6 NYCRR Part 661. The State tidal wetlands regulations generally are more comprehensive, including a 300-foot-wide regulated adjacent area. However, again, there are limitations; the adjacent area goes no further than the seaward side of an existing man-made structure, such as a bulkhead or seawall, and it calls for only a 75-foot-wide buffer

instead of 100 feet. Co-regulation would be beneficial in allowing more stringent controls or providing a venue for arranging compensation for wetland losses as is being done in the City of Rye.

Four of the six municipalities in WAC 5 have a local freshwater wetland ordinance. Three of the municipalities with ordinances--New Rochelle, Mamaroneck Town and Mamaroneck Village--base theirs on the State's Article 24 and its implementing regulations (6 NYCRR Part 663). New Rochelle's ordinance covers only state-designated wetlands, of which there is only one. Mamaroneck Town and Mamaroneck Village provide broader definitions, allowing control over smaller/local wetlands as well. Larchmont defines wetlands subject to local regulation by habitat and hydrology. Pelham and Pelham Manor do not have wetland ordinances. None of the municipalities have adopted local tidal wetland ordinances.

The existing freshwater wetlands ordinances were reviewed in comparison with A Model Ordinance for Wetland Protection (1988), prepared by the Westchester County Soil and Water Conservation District (SWCD). Other guidance used include: Stormwater Management Guidelines for New Development (1990), prepared by the New York State Department of Environmental Conservation (NYSDEC) (these guidelines are also known as Division of Water Technical and Operational Guidance Series 5.1.8); the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands, prepared jointly by the ACOE, the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service, and the U.S.D.A. Natural Resources Conservation Service; a Memorandum of Agreement (dated February 1990) between the ACOE and the U.S. EPA; and the NYSDEC's Reducing the Impacts of Stormwater Runoff (1992). No model ordinance currently exists for tidal wetlands. In Westchester County, only the City of Rye has adopted a local tidal wetlands ordinance.

While most municipalities with a wetland ordinance also regulate activities within an adjacent area of up to 100 feet, these "adjacent areas" do not carry with it the same weight as a true "buffer." A buffer is a protected area adjacent to a resource where certain activities or encroachment is prohibited. In the current ordinances, activities to be conducted within an adjacent area are merely brought under regulation; there are no prohibitions or standards to preserve adjoining areas as buffers to the wetland resource. Other features that are advocated in the model ordinance or guidance documents, but are missing or unclear in the existing ordinances, include: a scientifically-based methodology for delineating wetlands; specific standards for basing permit decisions; the requirement that wetlands only be used for final polishing if part of a stormwater management plan; mitigation sequencing requirements, which calls for wetland permit applicants to first demonstrate that wetland impacts cannot be entirely avoided, then to demonstrate that unavoidable impacts have been minimized, and finally to compensate for any remaining impacts; and a no net loss objective.

It is recommended that every municipality create or improve upon their existing freshwater wetlands ordinance by incorporating the SWCD model ordinance standards and the state and federal guidelines. Although Pelham does not have any freshwater wetlands within the subwatershed of WAC 5, it has wetlands along the Hutchinson River, which is part of the WAC 6 study area. It is also recommended that every municipality, except for Pelham which has no tidal wetlands, either adopt a local tidal wetland ordinance, allowing co-regulation with the State, or incorporate tidal wetland regulations into existing freshwater wetland regulations to extend protection to tidal wetlands.

Clearly, the first step in protecting water quality is to protect the wetlands themselves, both by enforcing applicable state regulations to their fullest extent and, where authorized by statute, by adopting local laws to protect wetlands and wetland functions. Following are some techniques for protecting wetlands.

Natural Vegetated Buffers

Natural vegetated buffers have tremendous value in protecting wetlands and surface waters from a variety of impacts. Buffer strips aid in reducing direct stormwater runoff discharge to surface waters, stabilize shoreline areas and provide wildlife habitat and corridors. Buffer strip widths may vary depending on the resource in question. For example, Queen Anne's County, Maryland, requires a 300-foot buffer around tidal wetlands and waters, 50 percent of which must be forested. If not currently wooded, trees must be planted. The non-wooded portion is maintained as natural ground cover.

Surface Water Discharges

Land development frequently results in increased discharges of surface runoff to wetlands and watercourses which may cause downstream flooding, severe alterations to wetlands hydrology, and degradation of water quality. To prevent this, direct discharge of surface runoff from roads and other paved areas to wetlands and watercourses can be prohibited by local ordinances. Developers can be encouraged to minimize the extent of paving within buffer zones and to use permeable paving materials where possible. Surface runoff should be recharged on site, using a combination of vegetated swales, detention basins and similar techniques (see also stormwater management and drainage controls under Subdivision Regulations, above).

Erosion and Sediment Control

The discharge of sediments to wetlands and waterways often has severe consequences, ranging from direct sedimentation of wetland flora and fauna to reduction in water quality. Therefore strict erosion and sedimentation controls for construction activities should be enacted. Different types of erosion controls will clearly be required for different slopes, soil conditions and construction activities. Subsequent revegetation requirements can also be specified, to insure long-term site stability.

Many guidelines have been developed which offer technical guidance, including the Westchester County Best Management Practices Manual for Erosion and Sediment Control (1991) and NYSDEC Division of Water's "Erosion and Sediment Control Guidelines for New Development" (Technical and Operational Guidance Series 5.1.10). In addition, the Soil and Water Conservation District produced A Model Ordinance for Erosion and Sediment Control (1986), which provides guidance for developing an effective local ordinance for controlling erosion and sediment.

Currently, Mamaroneck Town and Village have distinct ordinances for erosion and sediment control. New Rochelle, for projects above a certain threshold, requires compliance with the best management practices manual. These regulations include many of the features recommended in the aforementioned model ordinance, but not all. It is recommended that all municipalities adopt separate erosion and sediment control ordinances to ensure that all types of land development are required to implement proper controls. Those with such ordinances need only amend their existing regulations to incorporate some additional standards that would further strengthen these ordinances.

Restrictions on Pesticides and Fertilizers

Fertilized lawns often contribute substantial levels of nutrients, pesticides and herbicides to surface waters directly, via surface water runoff, and indirectly, via leaching to groundwater. Therefore, limiting the extent and controlling the location of lawns in any buffer adjacent to wetlands, streams, ponds and the Sound is recommended.

B. Non-Regulatory Tools

Many communities have recognized that over-reliance upon regulatory tools merely programs a municipality for development and allows little flexibility if the original program was inaccurate, or if better information has been made available since the program was devised. Consequently, an effective resource program should also utilize non-regulatory tools.

Although many non-regulatory water resource programs are available to cities and towns, they have traditionally focused on the categories noted below:

Land acquisitions, land donations, and conservation easements (the following three techniques) are all management techniques that may be more efficiently conducted by non-profit land conservation organizations than by municipalities. These organizations are frequently created as land trusts for particular towns, counties, or watersheds, and often have names such as "Smith County Land Trust," "Friends of Pleasant Lake," or "Jonesville Conservation Trust." These organizations are tax-exempt, not-for-profit corporations. Therefore, donations and bargain sales to the conservation trust are usually considered charitable donations and may have positive federal and state tax consequences. These organizations can provide expertise in arranging land transfers, drafting conservation easements, and explaining advantages and disadvantages of real estate transfers to both land purchasers and sellers; coordinate with and solicit aid from various foundations; and, in some cases, have the capacity to provide funds for acquisition or to serve as landowners and stewards. Some of these organizations can only serve as temporary landowners while others may hold lands permanently.

Land Acquisition

One obvious way for a community to protect a resource is to buy the land outright. Acquisition priorities may include wetlands and streambanks within coastal watersheds, often for access opportunities as well as for resource protection. Outright purchase of land can take four variations:

- a) Purchase at fair market value: The buyer (community or conservation group) pays the seller the fair market value for the property.
- b) Bargain purchase: The purchase of property below fair market value by a conservation organization or municipality. The difference between fair market value and the reduced price may qualify as a charitable deduction from income taxes for the seller.
- c) Installment purchase: The property is purchased over a period of years. Installment purchases allow the town to spread the purchase costs over a number of years.
- d) Purchase with a reserved life estate: The property is transferred to the town upon the death of the individual landowner. This option allows landowners to sell now, but to continue to use their property during their lifetime and/or the lifetimes of other members of their immediate family. Because of the continued use, the purchase price may be lower than fair market value.

An innovative technique for land acquisition is the land bank. Land banks receive a percentage of fees generated by real estate transfers, and use this money to fund land acquisition. Land banks are usually created by the state legislature and may apply to specific regions or statewide.

A more traditional, frequently controversial, form of land acquisition is through eminent domain. If a community can demonstrate the value of a given parcel for the public good, it can take ownership of that parcel. However, due compensation must be given to the previous owner, in accordance with the Fifth Amendment to the U.S. Constitution which states, "...nor shall private property be taken for public use

without just compensation." Public approval is usually required for eminent domain action, since public money is spent to compensate the previous owner. Eminent domain takings are frequently contested by the previous owner, who may believe the land to be worth more than is offered by the community.

Eminent domain takings should not be confused with a "takings" claim, where a landowner challenges a town that a zoning bylaw or other regulation prohibits him from all uses of his land, i.e., his land has effectively been taken without any compensation.

Land Donation

Landowners are often in the position of being able to donate a piece of land either to the community or a non-profit organization such as local land trusts. If so, they will find that giving the land for preservation costs them far less than they might think, particularly when a variety of tax savings are taken into account.

The initial benefit to the person donating the land comes in the elimination of estate or capital gains taxes. In addition, real estate taxes, insurance and maintenance costs are avoided. And, the entire value of the donation can be deducted, over time, from federal and, in many cases, state income tax obligations.

Donations of ecologically significant land with coastal watersheds can be a particularly important technique for resource protection. Donations which provide access to water often help fulfill community goals of increased public access to waterways.

Conservation Easements

An easement is a limited right to use or restrict land owned by someone else. Easements are either positive (rights-of-way) or negative (conservation, scenic) and may take a variety of forms. Easements can effectively assist a community in protecting land from development by restricting all or a portion of the property to open space or limited development uses. The granting of a conservation easement does not involve the transfer of ownership of the land; instead, it means giving up certain development rights of the property. For example, a conservation easement may restrict the number of houses to be built upon a parcel; restrict the types of development allowed on the parcel; or specify that portions of the parcel remain undeveloped in perpetuity.

Water Quality Monitoring

Water quality monitoring is becoming a very important aspect of a non-regulatory approach to water protection. Local governments have developed programs to identify problem areas in their community where contamination has already affected water quality. In addition, monitoring can be used to measure the effectiveness of the water protection program or as an early warning of threats. Monitoring can be conducted by state and local governments and water utilities, or industry and commercial entities may wish to develop their own water quality monitoring programs. Frequently, volunteers, particularly retired citizens and high school or university classes, can serve as effective resource quality observers.

For example, in Rhode Island, the volunteer Salt Pond Watchers monitor water temperature, clarity, nutrient, chlorophyll, and bacterial levels in coastal lagoons. The state Department of Environmental Management has used the Watchers Program data to determine shellfish and beach closures. In Chesapeake Bay, approximately 130 stations are monitored by volunteers for pH, dissolved oxygen, turbidity, water depth and temperature, air temperature, weather conditions, and rainfall.

Hazardous Waste Collection

Another non-regulatory protection tool is the collection of household hazardous waste. Although these materials are generated in small amounts, they can represent large threats to surface and groundwater quality. Motor oil allowed to drain onto the land surface when automobile oil is changed, excess paint discarded in the gutter, fungicides and herbicides left in a shed that is flooded during a hurricane are possible routes from contaminant container to water. To avoid these scenarios, many communities, including Westchester County, have implemented hazardous waste collection days. In other areas, these wastes are collected continuously. For example, in Arlington County, Virginia, the Water Pollution Control Plant accepts household hazardous wastes from residents. The Plant Chemist classifies and stores the wastes and periodically ships them to a licensed hazardous waste facility.

Public Education and Outreach

There are many examples around the country where innovative public education programs on water use issues have been developed. Public education can be used to build support for regulatory efforts, or to implement voluntary protection efforts such as water conservation, waste oil collection, and water quality monitoring. Public education and outreach are discussed further in the next chapter.

EDUCATION AND OUTREACH

A. Purpose

As part of any watershed management program, particularly one whose principle aim is to reduce nonpoint source pollution, an education strategy should be implemented to inform and educate the public about their role in controlling nonpoint source pollution. This strategy should be aimed at people who live and work in the villages, towns and cities comprising the watershed.

Public information and education are crucial components of any watershed plan. A large part of the strategy to curb nonpoint source pollution should be to educate the public about this form of pollution and the tremendous impact their attitudes and lifestyles can have on the quality of Long Island Sound and its tributaries. A public education initiative should teach citizens about the issues and problems of nonpoint source pollution and involve them in the solutions.

The Long Island Sound watershed in Westchester County is very diverse in its landscape and developed character and the people who live and work here. This diversity should be considered when developing an information dissemination and education strategy. An initial step in developing a public awareness program is to frame the message; determine what information about nonpoint source pollution is to be conveyed, and stress this message at every opportunity. The tone and level of complexity of the message depend on the community's composition and sophistication. The program should include concrete information about using and disposing of toxic substances in homes, yards, farms, and work places.

Nonpoint source pollution affects everyone in the community. On the issue of control, business people, developers and homeowners each have an individual agenda. A public awareness program should consider these individual needs and interests. Messages and presentations should be tailored to specific groups; for example, school faculty, city employees, developers, public and private organizations, and youth groups.

The following groups should be involved in the public awareness strategy:

- local government and community leaders
- residential property owners and tenants
- civic, environmental and other public and private organizations business and industry leaders
- grade school and college students and faculty

The table on the following page indicates the most effective use of various public education techniques.

PUBLIC EDUCATION TECHNIQUES

WATERSHED MANAGEMENT

METHOD	MOST EFFECTIVE USE	RESULTS
Newsletters	Announce meeting time and dates, update information on actions already taken, list issues to be discussed at upcoming meeting	Public awareness
Newspaper articles	Same as newsletter - provide additional detail about local stories, photos of citizen activities; feature articles provide information about problems and solutions	Public awareness
Demonstration sites	Exhibit innovative technology - should be accompanied by signs, brochures, or permanent on-site interpretive staff	Public awareness, knowledge, understanding
Printed and taped material (e.g., fact sheets, videos)	Explain new technology, describe case studies, provide training information for new employees, outline facts to stakeholders	Public awareness, knowledge, understanding
Signs	Mark watershed boundaries, identify critical areas, promote specific behaviors in specific places, identify cooperators in project, explain adjacent project and its BMPs, provide interpretive natural resources information	Public awareness, knowledge, understanding
Meetings	Share information, plan actions, evaluate process	Public awareness, knowledge, understanding, desire/ability to act
Field trips	Observe resources to be protected, view installed BMPs, learn how 13MPs operate, monitor (assessment or compliance type) 13MPs	Public awareness, knowledge, understanding, desire/ability to act
On-site inspections	Identify problems, recommend corrective actions, evaluate effectiveness of pollution controls, identify noncompliant stakeholders, educate individuals	Action
Training	Provide new skills to stakeholders	Action
Technical assistance	Identify problems, recommend solutions, assist with installation of BMPs, educate individuals, evaluate effectiveness of solutions	Understanding, desire/ability to act, action

Source: Terrene Institute, Clean Water in Your Watershed: A Citizens Guide to Watershed Protection, 1992

STORMWATER MANAGEMENT

A. The Nature of Stormwater Runoff

Stormwater runoff is that part of the total precipitation that flows over the ground. Under natural conditions, during and following precipitation, stormwater within a watershed flows to lower elevations where it is either recharged to groundwater or drains as runoff to streams, ponds, bays, and other surface waters. The amount of runoff from an undeveloped watershed area depends upon:

- storm characteristics
- type and amount of vegetative cover
- soils and soil permeability
- slope characteristics
- type and capacity of natural drainage systems

Storms are characterized by their

- duration (period of rainfall)
- total precipitation
- intensity
- frequency
- number of antecedent dry days

The number of antecedent dry days is one of the most important variables determining the amount of runoff and concentration of contaminants in stormwater due to its impact on the water storage capacity of soil and buildup of contaminants.

A portion of stormwater runoff also evaporates during overland flow and from surface waters. Recharge water (infiltration water) is that portion of stormwater that infiltrates the soil and moves downward to recharge the aquifers. A portion of the infiltration water is taken up by plants and lost to the atmosphere by evapotranspiration.

Due to the gradual percolation of much of the rainfall into the soil in relatively undisturbed watersheds, both the volume of runoff and rate of overland flow are reduced, thus maximizing aquifer replenishment in some areas and minimizing erosion. In developed watersheds, the amount of runoff also depends upon

- amount of impervious surface area
- existing stormwater control measures
- other factors

The presence of impervious surfaces and of stormwater drainage systems that conduct runoff from the site may increase the volume, accelerate the flow, and, in some cases, contribute to soil and streambank erosion. In areas where stormwater drainage systems have been installed, stormwater flows to stormwater management basins or other drainage structures for detention, extended detention, retention, or infiltration. In coastal areas, stormwater is sometimes discharged directly into surface water bodies or streams; in other cases, the overflow of drainage structures is directed into surface waters.

Stormwater as runoff or infiltration water is the vehicle by which pollutants move across land and through the soils to ground or surface waters.

Contaminants will accumulate or be disposed of on natural and urban land surfaces. Sources of contaminants include:

- animal wastes
- highway deicing materials
- decay products of vegetation and animal matter
- fertilizers pesticides air-borne contaminants deposited by gravity, wind or rainfall
- general urban refuse
- by-products of industry and urban development
- improper storage and disposal of toxic and hazardous material.

The contaminants associated with and carried in stormwater runoff include the following major categories:

- Metals
- Organic Chemicals
 - Base Neutral Compounds
 - Acid Compounds
 - Volatiles
 - Pesticides
- Organic Chemicals
 - Phosphates
 - Nitrates
 - Chlorides
- Bacteria and Viruses
- Oxygen Demanding Substances

Raindrops dislodge soil particles and contaminants from land surfaces. This material is then carried in solution or suspension and travels with the runoff. Suspended particles are deposited en route if/when the velocity of stormwater decreases. Contaminants carried in stormwater solution enter the soil through the larger pores at the soil surface and move downward and horizontally through the pore network. Water diffuses into the smaller pores by capillary or soil moisture tension. The rate of movement through the soils and surficial materials depends upon the size, shape, continuity and arrangement of the pore network system. The most soluble constituents such as nitrates and chlorides and many organic chemicals continue to move downward through the aquifer system or to the bays. Soils with a high clay, fine sand, or silt content or with the presence of interspersed clay lenses retard the rate of movement of water and some contaminants through the soil; contaminants may adsorb to soil particles. A portion of the nutrients and pollutants also may be used by plants and soil bacteria.

B. Stormwater Management Basins

Two major types of stormwater systems exist in Westchester: nonstructural and structural.

Nonstructural

Nonstructural systems attempt to deal with stormwater problems at their source. A variety of techniques are used to minimize stormwater runoff and erosion, maximize recharge and to maintain natural stormwater receiving areas. These include the use of:

- ecological and land use planning
- conservation easements
- zoning ordinances (establishment of the amount of site development and coverage)
- maintenance of natural vegetation
- the use of swales, depressions and other grading and planting techniques

Vegetative controls provide contact between stormwater runoff and vegetated areas and accomplish pollutant removal by a combination of filtration, sedimentation and biological uptake that reduce pollutant concentrations, and/or by a reduction in runoff volume due to infiltration and evapotranspiration.

Structural

Structural controls utilize built systems such as:

- stormwater sewerage systems
- detention basins
- extended detention basins
- retention basins
- infiltration basins
- sedimentation basins
- dry wells
- other systems

The treated water from these systems may be discharged into a stream or other surface waters.

Most of the runoff into stormwater management basins comes from impervious surfaces. Occasionally pervious surfaces are a source of runoff when the infiltration rate and water holding capacity are exceeded due to periods of high intensity rainfall. The so-called "first flush," or first half-inch of runoff from land which has been made impervious, delivers a disproportionately large load of pollutants during the early part of storms due to the rapid runoff of accumulated nutrients and pollutants. From 70 percent to 90 percent of the contaminants in stormwater can be removed by detaining the first flush of runoff.

Stormwater management basins can be classified into the following three categories:

- **Dry Basins** - These are basins with the outlet located at the bottom. They are almost always dry, except for relatively short periods following larger storm events. The outlet size is restricted to limit the maximum flow rate. Dry ponds are often used for flood and erosion control and are not as effective as extended detention and retention basins for water quality purposes. They may, however, be retrofitted to achieve water quality control.
- **Extended Detention Basins** - These basins employ an outlet structure that will cause stormwater runoff from most storms to pond in the basin. Following a storm, these basins drain in about 24 hours or more and will be dry at all other times. The outlet structures may be either perforated risers or subsurface drains. They provide a practical technique for retrofitting dry ponds to obtain water quality benefits, and can provide particulate (and the associated pollutant) removal efficiency nearly equivalent to that of wet ponds.

- Wet Basins - These basins employ outlet structures designed to maintain a permanent pool of water, which is not released except by means of evaporation, infiltration, or attenuated release when runoff volume exceeds the permanent storage capacity of the permanent pool. They can provide high removal efficiencies for particulates, and also have been observed to effectively reduce soluble nitrogen and phosphorus concentrations by means of biological activity.

C. Design of Structural Stormwater Management Basins

Proper management of stormwater requires informed judgment in order to interpret data and evaluate empirical runoff projections. Knowledge of the quantitative and qualitative characteristics of rainfall and the watershed is needed to permit the prediction of rates of runoff. Since there is considerable variation in the frequency, intensity and duration of rainfall, the designer must rely upon data derived from observations over long periods of time. Rain gauges have been used for almost a century to measure the intensity, duration and amounts of rainfall from specific storms. Historical records can be used to identify future probabilities.

Storm Characteristics

- Several general conclusions can be drawn concerning storms in Westchester:
- Intense storms usually cover small areas and are of short duration; storms of lower intensity tend to cover larger areas and are of longer duration
- Storms of high intensity and/or high total rainfall tend to have relatively lower frequencies of occurrence
- Storms of high intensity often cause flooding and damage due to erosion and sedimentation

Design of Closed Stormwater Drainage Systems

The most important consideration in designing stormwater control systems is to provide sufficient capacity to accommodate the peak rate of runoff. It is also necessary to determine the total amount of runoff for a given time period to insure adequate storage capacity of runoff. Stormwater drainage and stormwater systems are sometimes underdesigned due to high costs. The "rational method" is generally used as a first step for computing stormwater runoff for the design of closed stormwater drainage systems when the contributing area is less than 200 acres. This calculation method is based on selecting a design storm event that is characterized by its duration, average intensity and frequency of occurrence. This technique provides the average peak rate of runoff from a storm, but it does not provide a description of the actual storm. The formula for the Rational Method is $Q = CIA$ where:

- **Q** equals the amount of discharge (peak runoff rate) in cubic feet per second (CFS)
- **C** equals the runoff coefficients) of the drainage area
- **I** equals the intensity of rainfall inches per hour
- **A** equals the area of the watershed (acres)

Also considered in the design of stormwater management basins is the basin volume needed to store the required number of inches of rainfall. For instance, the volume of rainfall from a 5 inch storm for a 100acre watershed area would be determined as follows:

$$\begin{array}{rcl}
 \underline{5"} & & \\
 12"/ft & \times & 100 \text{ acres} \\
 & \times & 43,560 \text{ ft.}^2/\text{acre} \\
 & \times & \text{the runoff coefficient (0.30)} \\
 & = & 554,500 \text{ ft.}^3
 \end{array}$$

The storage area of the basin is then calculated.

Soil and surficial permeability rates are used to determine the capacity of stormwater management basins. The USDA-Natural Resources Conservation Service has classified soils into hydrologic soil groups ranging from hydrologic soil group A, which has a low runoff potential and a high infiltration rate, to soil group D, which has a very low infiltration rate. Soil storage capacity is dependent upon other soil characteristics in addition to the infiltration rate. For instance, a fine sandy loam may have the highest storage capacity but will have a lower percentage of large pores than a sand or loamy sand. A fine sandy loam has a high storage capacity because of soil moisture tension. It should be noted that once the recharge basin is in operation, the permeability rates may decrease due to sediment clogging of the soil pores or they may increase due to the establishment of vegetation and associated increased soil porosity. Test drilling should be performed at each proposed recharge basin site to determine whether there is a clay lens beneath the site.

Runoff Coefficients

Runoff coefficients refers to the percentage or ratio of runoff to the total amount of rainfall that will reach a stormwater management basin. A watershed that is completely forested and located on gentle slopes will have minimum runoff following a storm of relatively high intensity and duration due to the high retention capacity and low runoff coefficients associated with natural groundcover. A watershed that is primarily developed with extensive impervious surface areas has limited storage capacity and high runoff coefficients. The amount of runoff is a function of the amount of rainfall, amount of evaporation and plant evapotranspiration (seasonally variable), soil permeability, slope, and possibly texture of the surface area . Runoff from impervious surfaces usually varies from 80 percent to more than 90 percent. Therefore, the runoff coefficient as a ratio is 0.80 or 0.90 accordingly. The runoff ratios from pervious surfaces usually vary from 0.10 (natural vegetation) to 0.60 (compacted bare soils) or higher. The runoff ratio for a lawn or golf course is approximately 0.20 to 0.35. The coefficients used to calculate runoff from pervious surfaces may be low in some cases, particularly during a storm that occurs when the ground is frozen. If snow is present, runoff is further increased due to snow melt.

Key Problems

In the past, stormwater runoff systems were designed to get stormwater off the site and into stormwater drainage systems or onto roadways as fast as possible, sometimes at the expense of neighbors and downstream communities. Although a portion of the inland runoff was directed toward stormwater management systems, most of the stormwater and associated contaminants from areas adjacent to coastal waters were discharged untreated through drainage system outfalls and from roadways into surface waters and wetlands with impervious and modified pervious surfaces. Individual sites were developed without providing land for the recharge or treatment of stormwater and erosion control measures. Over time, this resulted in increased volumes and rates of runoff. Accelerated erosion and sedimentation were associated with the higher rates of runoff. An increase in runoff (and sedimentation) created the need for more extensive drainage systems to prevent the accumulation of water in streets and flood-prone areas. Since stormwater runoff is a transport vehicle for contaminants deposited on impermeable or relatively impermeable surfaces, it is often an important contributor to surface water degradation. To compound the problem, many coastal and inland wetlands were filled and developed, further reducing the storage area for stormwater, sediments and contaminants associated with the sediments. These conditions resulted in the following major effects:

- increased local expenditures for the installation and maintenance of stormwater drainage systems and roadway maintenance
- increased outlays for channel maintenance
- increased flooding of roads and of lowland areas resulting in hazardous driving conditions, dangerous flash floods and property damage

- loss of viable wetlands due to sedimentation
- increased concentrations of contaminants in groundwater
- the closing of a large portion of the area's shellfishing grounds due to high coliform concentrations introduced by stormwater
- changes in the values of aquatic and estuarine water quality parameters with possible adverse affects on aquatic and marine species

Health Related Problems

Although stormwater runoff may contain high concentrations of one or more contaminants, treatment is too infrequently provided before discharge into Westchester's surface waters. In a few areas a marsh pond or other biofiltration pond is used to trap some of the pollutants, thus allowing for reduction of indicator coliform bacteria and the partial uptake of some heavy metals and inorganic nutrients by plants.

A high coliform bacterial count in runoff is equated with the possibility that pathogens also may be present. While confined to storm drainage systems, runoff containing pathogenic organisms generally posed little direct threat to public health since stormwater is not ingested. When stormwater enters surface waters it can become a problem. The number of bacteria or viruses that can cause infection vary widely. Although thousands of viable bacteria may be needed to cause infection in humans, it is assumed that a single virus particle is an infective dose. Even though an infection occurs, it may not lead to disease, since the onset of disease is also dependent upon the age, general health and degree of immunity of the host.

Impacts Upon Estuarine Waters

Stormwater runoff and stream base flow are important sources of pollutant loadings to Westchester streams, ponds and bays. Two categories of runoff to estuarine waters have been observed: upland runoff entering the freshwater portions of streams and conveyed thereby to the Sound, and overland runoff that enters the Sound (or the tidal portions of the streams) usually by direct overland flow or storm drainage systems. Impervious surfaces constitute the major source of stormwater runoff to streams and bays, but some runoff from pervious surfaces also occurs.

Stormwater runoff has been associated with high concentrations of bacteria in estuarine water and the closing of shellfishing areas due to high indicator bacteria counts. A study on Long Island involved monitoring bacterial counts following storms in freshwater streams and ponds, at discharge points to estuarine waters, and in bays during and following storm events. It was calculated that stormwater runoff accounted for at least 93% of the total and fecal coliform discharge. Sedimentation rather than bacteriological die-off appears to be the mechanism for the attenuation of bacteria in stormwater runoff **from** ponds before discharge into marine water.

Nitrogen and phosphorus from fertilizers and other sources enter fresh and marine waters by stormwater runoff, stream flow and groundwater flow. Elevated nitrogen levels can result in phytoplankton bloom and rooted aquatic growth (e.g., eelgrass), since nitrogen is a limiting growth factor in estuarine waters.

Impacts Upon Fresh Surface Waters

Biological monitoring has been used to measure the impact of stormwater upon aquatic communities. Increased pollution in urban ponds and streams has resulted in marked changes in the type and number of species present. High concentrations of phosphorus from fertilizers applied to landscaped areas and phosphorus from other sources in the immediate watershed area can result in algal blooms and other eutrophic conditions.

The depletion of oxygen as measured by high biological oxygen demand (BOD) values in receiving waters is one of the most important impacts on freshwater systems. When high BOD loadings are discharged to surface waters, the resultant depressed oxygen levels eliminate those species that cannot survive at low oxygen levels. Aquatic life changes over time as high oxygen demanding species are replaced by those that can tolerate lower dissolved oxygen (DO) levels. This is an especially important problem in lakes and ponds. A pond that once had species indicative of good water quality such as mayflies, stoneflies and caddisflies may now have large numbers of worms such as Tubifex and Limnodrilus udekamianus. Other types of worms may be present that have special types of blood or breathing mechanisms that allow them to adapt to waters with low DO levels.

Grease and oil products are sometimes disposed of on the land, into storm sewers, or directly into surface waters. If sufficient concentrations of these products are found in the water column or accumulate on aquatic plants, they can harm or kill aquatic biota. High concentrations of salts from highway deicing practices also may also impact aquatic vegetation and aquatic ecosystems.

Basin Bank Stabilization

One of the most important features to include in basin designs and bank stabilization is to establish a vegetative buffer around stormwater management basins. The establishment of a vegetative buffer, utilizing a diversity of native plant species, is the most practical and cost efficient alternative to protect and prevent degradation of detention ponds. Vegetative buffers should be established at or near the shoreline and continue landward for a desired distance ranging in size from 20 to 30 feet for most urban basins to 100 feet or more depending on the management objectives. Aquatic plant species also may be established in shallow water areas, or benches, along the shoreline. A vegetative buffer around the perimeter of a detention, extended detention or retention basin serves to:

- reduce stormwater runoff from adjacent lawns, roads, and rooftops by encouraging infiltration
- stabilize the banks and shoreline of the basin to prevent soil and bank erosion
- filter nutrients and contaminants from runoff to prevent water quality degradation
- provide shade for aquatic species and reduce the effects of thermal pollution
- provide fish and wildlife habitat for feeding, breeding, avoiding predators, and shelter
- maintain a diversity of native plant species, including grasses, herbs, shrubs and trees
- discourage large nuisance flocks of Canada geese and gulls, who do not like habitat with taller grasses, shrubs or trees

D. Existing Management Practices: Local and State Controls

Stormwater runoff management in Westchester generally consists of local laws and ordinances, standards and guidelines for stormwater collection systems that are predominantly structural in nature. These standards and guidelines are based on the premise that watershed characteristics and various types of development will produce specific quantities of runoff. Collection systems are based on design standards and engineering practices that include the use of empirical formulas (such as the "rational method"), the construction and use of stormwater management systems according to a specified storage capacity (number of inches of rainfall), or the use of leaching systems, catch basins, dry wells or other structures deemed appropriate. The use of these standard structural systems has generally been successful. However, they have not always proved to be the best in respect to long-term environmental impacts, are implemented too infrequently, and are not the most cost beneficial in terms of maintenance costs.

A comprehensive approach to stormwater runoff management, in which performance standards and site development techniques are used to protect a site's natural resources and downstream watershed, is becoming more widely accepted. Drainage designs are increasingly based upon individual site characteristics and watershed management goals. This type of approach implements certain stormwater management objectives, such as preserving the integrity of natural drainage patterns to prevent flooding and damage to stream channels or other surface waters. It also requires adherence to standards that will insure the attainment of these objectives. The requirement that stormwater runoff from a developed site not exceed that generated under natural or undisturbed conditions is an example of such a standard. In this instance, developers are not required to install a specified type of drainage facility but are given the flexibility to choose the stormwater management system best suited to the needs of each development, subject to the requirements of a performance standard. The type of system that should be installed will be determined by the system's effectiveness given the variations of:

- slope
- lot size
- vegetation
- water resources
- soils
- type of development under consideration

The State Environmental Quality Review Act (SEQRA) review process can be used on a local level to incorporate environmental concerns, including stormwater management, into the planning and decision making processes for development. According to SEQRA, each municipality can, under its own local law, provide a list of those critical environmental areas (CEAs), such as existing natural drainage systems, flood prone areas, wetlands and watercourses (and associated uplands), and/or steep slopes or areas prone to erosive forces where potentially hazardous or harmful environmental impacts may occur. Following CEA designation, the potential impact of any Type I or Unlisted Action on the environmental characteristics of the CEA is a relevant area of environmental concern and must be evaluated in the determination of significance of adverse environmental impact. This local review procedure can become a tool for the protection of the environment from the adverse impacts of inadequate or improperly designed stormwater controls.

E. Generalized Recommendations

Regulations and Administration

The following recommendations comprise preventive measures that can be used to minimize stormwater contamination of surface waters and groundwater resulting from site development and future land use activities as well as suggestions for reducing or eliminating existing impacts. For specific recommendations for municipalities in the WAC 5 study area, see Section I of this plan. Criteria are also provided for the selection and installation of appropriate stormwater control measures including both nonstructural and structural techniques. This section also describes a number of management practices, erosion and sediment control measures and the suitability of these measures for various types of site conditions.

Municipalities, County and State

- On publicly-owned lands adjacent to surface waters and wetlands, limit development and the establishment of impermeable paving.
- Prohibit any new direct discharge of stormwater runoff into surface waters or freshwater or tidal wetlands.

- Evaluate existing stormwater systems that currently discharge into surface waters to determine whether the systems can be modified to include additional control measures to minimize impacts on surface waters and adjacent areas:
 - Inventory direct discharges and assign remediation priority ratings based upon environmental impacts.
 - Determine if there is sufficient land area to develop cost-effective energy dissipation areas and sediment basins as well as extended detention or retention basins to eliminate or reduce direct discharge and accompanying nutrient, pollutant and sediment loadings to surface waters and wetlands.
- Local governments need to develop more complex design requirements for stormwater management basins and wetlands. The frequent practice of specifying a fixed treatment volume may not be sufficient to assure reliable pollutant removal. Local governments may wish to develop additional design criteria to improve pond and wetland performance. These might include requirements for sediment forebays, minimum length to width ratios, redundant treatment techniques, and greater structural complexity for wetlands.
- Ensure adequate long-term maintenance of stormwater management basins through public acquisition, easements or permit/approval conditions. The retention and maintenance of these areas will facilitate the recharge and treatment of runoff, thus reducing the amount of stream flow following a storm and the subsequent associated high coliform loadings that would otherwise reach the bays. A reduction in coliform loadings to the Sound can be achieved through the use of basins to retain sediments thus allowing for the die-off of most coliform bacteria.
- Do not mow or remove vegetation in or adjacent to stormwater management basins unless such removal is part of a prescribed maintenance program because plant growth generally enhances infiltration and nutrient/pollutant removal.
- Incorporate the erosion and sediment control recommendations into municipal law (see separate municipal laws section).
- Require adherence to the following performance standards for all new site development:
 - Protect and maintain the natural functions of the site by maintaining the absorptive, purifying and retentive functions that existed on the site before construction began.
 - Limit the post-construction volume and rate of runoff leaving the site to that calculated on the basis of natural or predevelopment conditions. The peak release rate of stormwater from all developments where retention is required should not exceed the peak stormwater runoff from the area in its undeveloped state for a storm of any intensity up to and including the 100-year frequency, and for rainfall of any duration. Calculations of the rate should be based upon an assumed runoff coefficient of 0.20, 0.25, and 0.35 for average slopes of 2 percent, 2 to 7 percent, and more than 7 percent, respectively.
 - Design the site stormwater system so that the runoff release rate from natural drainage channels will not exceed the natural carrying capacity of the channel.
 - Limit the release rate for stormwater systems serving new development. The volume and velocity of runoff discharged should not exceed the safe capacity of the existing drainage systems into which the discharge flows.
- Require a stormwater management plan for any property when
 - a plat is to be recorded
 - land is to be subdivided
 - an existing drainage system may require alteration

Site Planning Recommendations

Success in the reduction of stormwater related impacts and the costs of installing stormwater systems depends, in large measure, on proper site analysis and the selection and placement of development suited to the site.

- Undertake a careful site analysis to identify any developmental constraints affecting the design of a stormwater control system that may be imposed by the location of existing on-site and off-site features.

The site analysis process should include the following steps:

- Prepare a key map locating the site within the watershed
- Prepare a watershed analysis map showing the site drainage system in relation to the watershed. Locate all natural drainage swales, depressions, steep slopes, high points, low points, flood prone areas, areas with depth to seasonal high water table less than six feet, areas of existing vegetation, sensitive wildlife habitats, and soil constraints. Stormwater impacts can be minimized by avoiding soil conditions with severe or moderate constraints.
- a *slight constraint* indicates no limitations or a few that can be overcome with relatively little cost.
- a *moderate constraint* indicates limitations that are more difficult and expensive to correct.
- a *severe constraint* indicates the soil is very poor and will require replacement filling or modification if used (filling is not recommended).
- Locate on-site areas suitable for the treatment of stormwater
- Locate on-site areas suitable for development. Site building and paved areas only where the presence of the environmental conditions are favorable. The following soil and slope conditions may indicate soil suitability for development:
 - nearly level or moderately sloped terrain; (less than 15 percent gradient)
 - moderately to rapidly drained soils; (moderate to high permeability rate)
 - a coarse or medium textured soil
 - a seasonal high *water table* more than six feet below the surface
 - other soil listed under *slight* constraints in the USDA-NRCS Soil Survey of Putnam and Westchester Counties (1994).

Use proper site design, including the following:

- Minimize grade changes and site clearing
- Retain native vegetation on steep slopes, in swales, on soils with a high content of silts, fine sands and clays, and in areas with a high water table or adjacent to surface waters.
- Avoid the use of paved surfaces such as parking lots and roadways where the presence of the following conditions indicate potential problems:
 - severely sloped terrain
 - floodplains
 - existing swales
 - depressions or lowlands
 - soil constraints listed as *severe* or *moderate*
- Incorporate the following general stormwater controls checklist into the site design as needed to meet the performance standards listed:
 - Reduce the extent of impermeable surfaces insofar as possible.
- Use swales and shallow depressions to collect stormwater on-site, wherever possible.
- Preserve swales in their natural state; avoid disturbance of existing grades, vegetation (particularly ground cover) or soils and the alteration of surface hydrology.
- Provide temporary on-site areas to receive stormwater runoff flows that are generated by construction and other site development activities.
- Do not allow increased sediment resulting from the construction or operational phase of site development to leave the site or to be discharged into stream corridors or tidal or freshwater wetlands.
- Minimize the amount of soil area exposed to rainfall and the period of exposure. Cover or plant exposed soils as soon as possible.

- Do not allow the dumping or filling of excess soil or other materials generated from site development into swales and surface waters.
- Detain runoff on-site and direct stormwater from road surfaces to sediment basins before discharge to a sump wherever topography limits or precludes on-site detention or retention. At sites where vertical drainage is not feasible, all runoff from a 25-year frequency, 24-hour storm from unstabilized soil areas should be collected, desilted, and released into stable channels at an acceptable design velocity appropriate for channel characteristics.

Once the site plan has been partially completed, undertake the following steps:

- Calculate the amount of stormwater entering the site
- Calculate the amount of natural runoff from the site
- Calculate the additional amount of runoff due to the proposed installation of impermeable paving and other surfaces
- Locate areas on-site for the storage and recharge of stormwater
- Re-evaluate the site plan if the storage and recharge area capacity is not sufficient.

Combine Development and Stormwater Controls

- Use cluster development as a viable alternative to conventional subdivision layout to preserve environmentally sensitive qualities of wetlands, aquifer recharge areas, swales and woodlands.
- Reduce the length of roadways, thereby reducing the extent of cut and fill and stormwater runoff volumes and minimizing the possibility of erosion/sedimentation.
- Reduce the area of other impermeable surfaces such as walkways, patios and recreational facilities.
- Allocate open space for recreation and water quality protection.

Natural Vegetation

- Use natural vegetation as an important nonstructural alternative in the control of stormwater runoff and erosion/sedimentation. Natural vegetation includes woodland, free-standing trees, old fields, unmowed grasses, and wetlands. When left undisturbed, vegetation stabilizes steep slopes, streambanks, and drainage ways by:
 - Reducing stormwater velocity, allowing for absorption of water by soils to occur, thus recharging the aquifer below and allowing for greater filtration of nutrient-rich and contaminated water.
 - Acting as a filter by trapping sediment particles.
 - Holding soil particles in place.
- Identify site locations where existing vegetation will not be disturbed by grading, filling or removal; removal exposes valuable topsoil, making it highly susceptible to erosion/ sedimentation.
- Stabilize exposed slopes during and after construction, by using temporary and/or permanent, structural or nonstructural stabilization measures. All areas not to be covered with an impervious surface should be temporarily stabilized immediately following disturbance. Permanent stabilization measures should be installed as soon as possible.

Natural Depressions

- Use natural depressions to collect runoff from the surrounding development and slow its velocity, allowing for recharge. Natural depressions consist of gently sloping land, vegetated with grasses, understory vegetation, and/or trees. Depressions also function as runoff holding areas, allowing sediment particles and debris to settle out before discharge to nearby surface waters. Except during storm events, depressions also may serve as recreational open space.

Wetlands

- Do not discharge untreated stormwater runoff directly into tidal or freshwater wetlands, and do not construct stormwater management basins in naturally-existing wetlands.

Stormwater Detention

- Use stormwater extended detention (temporary detainment of stormwater runoff, with gradual release to surface or groundwaters) to maintain the same volume and rate of site runoff after development as that which existed prior to the development. Extended detention basins are designed to drain completely 24 hours or more after a storm. An emergency spillway should be provided to allow release of runoff during storms that exceed the design capacity of the retention area. Except during storm events, detention areas also may serve as open space and should be as visually attractive as possible.
- Maintenance of the control facility should be provided to insure sustained flow rates and visual attractiveness.

CASE STUDY: STORMWATER MANAGEMENT BASIN RETROFIT

In the early 1970s, nuisance algae blooms and low dissolved oxygen problems began to plague the Loch Rave Reservoir in Maryland. The cause was an overload of phosphorus generated by agricultural activities and urbanization.

Baltimore County had several phosphorus control programs, but of limited effectiveness. In urban areas, the programs focused mainly on retaining stormwater, primarily via 36 dry detention basins that became inundated only during large storms. Because the hydraulic controls were designed to accommodate only large flows, most stormwater runoff and the sediments, nutrients and contaminants it carried passed through the basins unimpeded. Thus, the basins did little to enhance water quality and the reservoir suffered.

To combat this problem, officials started modifying stormwater basins to detain flows from small storms without compromising the basins' ability to control large storm flows. Before modification, the 36 structures could control stormwater flows from storms that generally occur every two years, 10 years and 100 years. But because most storms are less intense than even the two-year type, engineers and planners needed to adjust the structures to accommodate smaller storms.

To modify the structures, engineers took a two-pronged design approach. First, they needed to know how small the basins could be without restricting their capacity to control runoff from larger storms. Through computer modeling, it was determined that the basins could be modified to accommodate one-year storms - even smaller storms would not be short-circuited. Second, the engineers needed to design the actual retrofits, which would vary the size of the low flow release structure to handle small storms. This was accomplished by designing a special attachment and installation of a trash debris guard.

Each retrofit was tailored to individual outlets and site conditions. Many of the retrofits completed to date are dry basins whose retrofits took less than three days. Retrofitting the wet basins is more complicated and expansive because the basins had to be pumped and their bottoms dredged to uncover the low flow releases from sediment. The wet basins took about a week to retrofit.

Results indicate that the retrofits remove more than 90 percent of all particulate matter (suspended sediment) and up to 40 percent of the total phosphorus and nitrogen. None of the retrofits clogged, demonstrating the effectiveness of the trash-debris guards. Sediment in-filling has not been appreciable

despite the basins' estimated high trap efficiency. This is most likely due to the fact that all of the retrofits drain stabilized urban areas that characteristically have low sediment export rates. Sediment infilling is expected to be a concern in areas with construction activity.

Stormwater Retention Ponds

- Stormwater retention should be used to permanently hold stormwater runoff on the site or for long term detention to allow for the die-off of coliform bacteria. Retention basins can provide recreational and aesthetic benefits for development by supporting certain native plants and aquatic life. They also can provide a habitat for wildlife when the pond is planted with upland and aquatic vegetation. The retention pond should be sized to contain both the normal dry weather water volume and expected runoff flows. It is recommended that the retention pond be designed to accommodate a 100-year, 24-hour storm. In areas where heavy sediment loads are anticipated, the aesthetic value of the permanent ponds and its surroundings will be severely reduced by deposited sediment and debris. Therefore, maintenance will be required or a more easily maintained sediment basin should be constructed immediately upstream from the basin.

Drainage Channels

- Naturally-vegetated swales or other types of drainage channels should be used to carry stormwater. Use grassed or vegetated waterways in areas where design velocities are low and soils have a low erosion potential. Stabilized vegetation also reduces the energy of flow, allowing for infiltration of runoff. Vegetative waterways are usually preferred over structurally-lined channels for reasons of aesthetic value.
- Bare channels should be used only as a temporary measure for construction sites in areas where the slope is minimal, and the runoff velocity is low. Do not install bare drainage channels in areas with highly erodible soils. The permanent use of bare channels should be avoided.
- High or runoff velocities and concentrations are erosive, particularly in areas of highly erodible soils that preclude the establishment of vegetative cover. The most common structural linings include stone rip-rap.
- Shallow detention and recharge areas should be used upgradient of natural swales as required so that the existing volume and velocity of runoff into the swales is not exceeded. If this is not possible due to lack of land area or the presence of a high water table, etc., then vegetative and/or structural stabilization measures will be required to provide the swale with the capability to carry and/or recharge runoff without risk of erosion/sedimentation.
- Protect the channel until a uniform vegetative cover has been obtained, eliminating the risk of erosion and/or sedimentation damage. Common channel stabilization methods include the use of seeding, mulches, and sod. Jute netting and other mulching techniques are frequently used to protect channels until vegetation is established.

Diversion Control Measures

- Use diversion control measures to direct stormwater away from an area where it could cause damage from flooding erosion and/or sedimentation. A surface drainageway is one type of a diversion control measure. It is a natural or constructed channel or waterway used to divert stormwater runoff. A berm is another type of diversion control measure. Surface drainageways and berms should be used to divert stormwater away from natural slopes where slopes or soils were exposed during construction and newly constructed fill slopes. Channels and waterways should have the capacity to provide a path for flow to move at non-erosive velocities to a stable outlet. Diversion control measures should not direct stormwater runoff to an adjacent property.

Energy Dissipation

- Use energy dissipation devices to slow the velocity of stormwater runoff to a non-erosive rate. This can be done by establishing a control area immediately adjacent to an outfall or other discharge point. Usually a pile of rocks, stones, gravel/crushed stone or boulders is used to reduce the velocity of the stormwater as it moves through the area. Energy dissipaters may also serve as sediment filters, trapping suspended particles and debris.

Sediment Basins

- Use sediment basins to protect surface waters from increased sediment loads by trapping the suspended solids before the runoff is released.
- Remove accumulated sediment and debris periodically, so that the basin will function properly and its visual attractiveness will remain. Wherever possible, retain vegetation because the roots can increase soil permeability.

Biofiltration Systems

- Use a biofiltration system to detain runoff and reduce contaminant loadings. Biofiltration by a combination of physical and biological processes can minimize concentrations of coliform bacteria, heavy metals, and nutrients carried in stormwater runoff. A biofiltration system is essentially a manmade pond or wetland. The system includes an energy dissipater, located below the inlet pipe, to reduce water velocity and trap suspended solids (sediment and debris). The entire basin is lined with an impermeable vinyl sheet or clay layer to prevent leaching of trapped contaminants to groundwaters. The vinyl or clay is covered with clean sand and loam, and planted with indigenous aquatic plant species, such as *Typha angustifolia*, or cattails. All above-water areas are stabilized by plantings of rye grass, *Lolium multiflorum*, or Tall Fescue, *Festuca arundivacea*, or Red Fescue, *Festuca rubra*, to name a few. Removal of pollutants is accomplished as the runoff moves across the plants. After a detention time of several days, during which the contaminants are absorbed by the plants, significant reductions in contaminant levels occur. The treated runoff is then released to adjoining surface waters. The overflow chamber, located at the pond outlet, (equipped with backflow and adjustable weir) controls the storage capacity. Maintenance involves the periodic cleaning of the surge tank and overflow chamber of floating debris and sediments, and biannual harvesting of aerial portions of the aquatic plants.

Permeable Paving

- Use permeable or "porous" paving for patios, walkways and parking lots to reduce the volume of stormwater runoff by increasing infiltration to the ground below, thus allowing for recharge of the aquifer. Permeable paving may be used in areas where permeability of the soil is sufficient to allow rapid drainage and where a seasonally high water table is not anticipated.

WETLAND AND STREAM BUFFERS

A. Natural Water Filters

A relatively simple way to reduce or eliminate impacts to aquatic resources from adjacent land uses is to maintain buffers around the resources. *Buffers* are vegetated zones located between natural resources and adjacent areas subject to human alteration. In some locations, a buffer may be referred to as a *vegetated filter strip*. The emphasis on the filtering functions of buffers is derived from their widespread use to remove sediments and other waterborne nutrients and pollutants from surface runoff.

In general, riparian and wetland buffers do the following:

- moderate runoff and stream temperatures (runoff from pavement is significantly warmer than runoff that passes through soil and vegetation, and trees provide shade for streams);
- control the velocity, quantity and quality of stream flows;
- enhance wildlife habitat diversity;
- stabilize streambanks and reduce channel erosion;
- regulate channel shape and size, reducing potential future impacts on adjacent properties;
- provide principal energy source for the base of the food chain (detritus/leaf litter);
- enhance food web and species richness;
- reduce potential formation of fish migration barriers (shallow areas and accumulated sediment);
- enhance recreational opportunities;
- attenuate nitrogen from shallow groundwater flows to streams;
- mitigate the effects of watershed imperviousness;
- increase property values;
- allow for future restoration/reforestation of stream corridors.

Recent research has shown that stream and wetland buffers can improve the quality of water resources by removing or ameliorating the effects of pollutants in runoff and increase the biological diversity and productivity of stream and wetland communities by improving habitat and adding to the organic food base. Forest buffers can function, often simultaneously, as filters, sources, transformers and sinks.

Forest buffers filter sediment and other suspended solids from surface runoff. Sediment is probably the most common and most easily recognized of the nonpoint source pollutants. Sediment suspended in the water can reduce or block sunlight penetration, adversely affecting the growth and reproduction of beneficial aquatic plants. Sediment deposited on stream bottoms can interfere with the feeding and reproduction of bottom dwelling fish and aquatic insects, weakening the food chain. Large deposits of sediment can overflow stream channels and floodplains, greatly increasing the potential for flooding. Furthermore, nutrients and pollutants adsorb to sediment particles. When sediment is transported via erosion, these nutrients and pollutants also are transported.

Several mechanisms of sediment removal work in the streamside forest. Some sediment settles out as the water flow speed is reduced by the many obstructions encountered in forest litter. Additional sediment is filtered out by the porous soil structure, vegetation and organic litter as the runoff flows over and into the floor of the forest buffer.

Phosphorus also is reduced by the filtering action of the forest buffer because about 85 percent of available phosphorus is bonded to the small soil particles comprising the sediment. Approximately 4 percent of the phosphorus is attached to soil particles too small to be filtered by these processes resulting in a removal of about 80 percent of phosphorus by the forest filter. The minor amount of ammonium which is bound to sediment can be filtered out in the same way. Nitrogen, too, is filtered out in large amounts by the buffer. However, dissolved phosphorus and nitrate must be removed by either microbial or biochemical transformation processes.

The forest buffer also acts as a transformer when chemical and biological processes within it change the chemical make-up of compounds. For example, under oxygenated soil conditions, bacteria and fungi in the forest buffer convert nitrogen in runoff and decaying organic debris into mineral forms. These forms can then be synthesized into proteins by plants or bacteria. When soil moisture is high enough to create anaerobic conditions in the litter and surface soil layers, denitrifying bacteria convert dissolved nitrogen into various nitrogen gasses, returning it to the atmosphere. Studies have shown that the amount of nitrogen in runoff and shallow groundwater can be reduced by as much as 80 percent after passing through a forest buffer.

The forest buffer further acts as a transformer when toxic chemicals such as pesticides are converted to non-toxic forms. Because of continued improvements in the formulation and management of pesticides, only very small amounts manage to leave the area of application. These residues, borne by runoff, are converted to non-toxic compounds by microbial decomposition, oxidation, reduction, hydrolysis, solar radiation and other biodegrading forces at work in the soil and litter of the buffer.

The forest buffer also functions as a sink when nutrients are taken up by plants and sequestered in plant tissue. Some estimates indicate that 25 percent of the nitrogen removed by the forest buffer is assimilated in tree growth which may be stored for long periods of time in woody tissue and possibly removed as logs or other forest products. Nitrogen and other nutrients also may be passed up the food chain when plant tissues are consumed by animals and converted to animal tissues. In wetter areas, nutrients in leaf litter can be stored for longer periods as peat. Sediments filtered out by the buffer remain to become incorporated into the forest soil.

Four criteria have been identified for determining adequate buffer sizes for aquatic resources: (i) resource functional value, (ii) intensity of adjacent land use, (iii) buffer characteristics, and (iv) specific buffer functions required. Generally, smaller buffers are adequate when the buffer is in good condition (e.g., dense native vegetation, undisturbed soils), the wetland or stream is of relatively low functional value (e.g., high disturbance regime, dominated by non-native plants), and the adjacent land use has low impact potential (e.g., parkland, low density residences). Larger buffers are necessary for high value wetlands and streams that are buffered from intense adjacent land uses by buffers in poor condition.

B. Buffer Size Requirements

The range of generally appropriate buffer widths for several buffer functions is variable depending on the biological, chemical, and physical characteristics of the buffer. Figure 1 provides a schematic presentation of buffer widths in relation to specific pollutant reduction goals. The results illustrate that buffer sizes may vary widely, depending on specific desired functions and buffer characteristics.

Figure 1. Range of buffer widths providing specific buffer functions.

water temperature moderation	sediment removal	nutrient removal	species diversity	
35(ft)	100(ft)	165(ft)	230(ft)	295(ft)

C. Sediment Removal and Erosion Control

Vegetated buffers control erosion by blocking the flow of sediment and debris, by stabilizing streambank and wetland edges, and by promoting infiltration (Shisler et al., 1987). Buffer vegetation forms a physical barrier that slows surface flow rates and mechanically traps sediment and debris. Roots maintain soil structure and physically restrain otherwise erodible soil. Because flow rates are generally lower for sheet flow than for channelized flow, vegetation resists the formation of channels (water will flow more slowly over vegetation, allowing more time for settling of sediments and infiltration).

Wong and McCuen (1982) derived an equation to determine effective buffer widths, based upon sediment particle size, slope, surface roughness, and runoff characteristics. While small buffers were found to remove small amounts of sediments, the relationship between buffer width and percent sediment removal was nonlinear; disproportionately wider buffers were required for incrementally greater sediment removal. For example, if the design criteria for sediment removal were increased from 90 percent to 95 percent on a 2 percent slope, then the buffer widths would have to be doubled from 100 feet to 200 feet.

Young et al. (1980) found that a 80-foot-wide vegetated buffer reduced the suspended sediment in feedlot runoff by 92 percent, but Schellinger and Clausen (1992) determined that a 75-foot-wide buffer removed just 33 percent of the suspended solids from dairy farm runoff. Homer and Mar (1982) reported that a 200-foot-wide grassy swale removed 80 percent of the suspended solids and total recoverable lead; Broderson (1973) also found that 200-foot-wide buffers effectively control sedimentation, even on steep slopes. According to Lynch et al. (1985), a 98-foot-wide buffer between logging activity and water resources removed an average of approximately 75 percent to 80 percent of the suspended sediment in stormwater. Greater sedimentation resulted from forested areas that had been commercially clear-cut and then denuded with an herbicide because of channelization, which developed following these activities. Ghaffarzadeh et al. (1992) examined sediment removal by grass vegetated filter strips ranging from 0 to 60 feet on 7 percent and 12 percent slopes. They found no difference in vegetated filter strip performance on either slope beyond 30 feet, where 85 percent of the sediment was removed.

D. Excess Nutrient and Pollutant Removal

Buffers remove pollutants and excess nutrients from runoff, but the rate of removal appears to be a function of the length, slope and soil permeability of the buffer, the size of the contributing runoff area, and the runoff velocity. Therefore, recommended buffer widths for nutrient and pollutant attenuation vary widely. In general, the recommended width is 100 feet or more. However, few opportunities exist in the WAC 5 study area to establish 100-foot-wide buffers. Fortunately, some research indicates that lesser buffers may contribute significantly to the reduction of nonpoint source pollutants. Madison et al. (1992) examined the ability of grass vegetated filter strips (VFSs) to reduce nitrogen and phosphorus during two simulated storm events (the equivalents of the 1-year and 10-year events). Grass VFSs which were 30

feet wide had trapping efficiencies of between 96 percent and 99.9 percent. Vegetated filter strips wider than 30 feet did not result in further improved trapping efficiencies, according to Madison. Dillaha et al. (1989) reported that 30-foot-wide and 15 foot-wide VFSs removed an average of 84 percent and 70 percent of suspended solids, 79 percent and 61 percent of phosphorus, and 73 percent and 54 percent of nitrogen, respectively. Xu et al. (1992) found that nitrogen concentrations were reduced from 764 mg to approximately 0.5 mg in a 30-foot-wide mixed herbaceous and forested buffer strip in the North Carolina Piedmont. Wooded riparian buffers in the Maryland coastal region were found to remove as much as 80 percent of excess phosphorus and 89 percent of excess nitrogen, most of it in the first 62.3 feet (Shisler et al. 1987). Schueler (1987) suggested that, as an "absolute minimum," an unmanaged/unmowed grass strip should be at least 20 feet wide, but better performance is achieved if the strip is 50 feet to 75 feet wide, plus an additional four feet per each 1 percent of the site's slope.

E. Moderation of Stormwater Runoff and Water Temperature

Wetland and stream buffers affect the quantity as well as the quality of stormwater runoff. A vegetated buffer zone that resists channelization is effective in decreasing the rate of water flow and, in turn, increasing the rate of infiltration (Broderson, 1973). Bertulli (1981) concluded that adjacent forest vegetation and litter lowered stream water elevations from 32.3 feet to 17.3 feet for a 100-year flood.

Forested buffers adjacent to wetlands provide cover, thereby helping to maintain lower water temperatures in summer and lessen temperature decreases in winter. Broderson (1973) found that 50-foot-wide buffers provided adequate shade for small streams; further, buffer widths along slopes can decrease with increasing tree height with no significant loss of shading. Lynch et al. (1985) determined that a 100-foot-wide buffer from logging operations maintained water temperatures within 2 to 3 degrees Fahrenheit of their former average temperature.

WETLAND RESTORATION AND CREATION

By the mid-1980s, the idea of restoring and creating wetlands began to be seriously considered as a means of mitigating wetland losses and meeting the "no net loss" goal. Proponents believe that these practices can offset the annual loss of natural wetlands.

A. Success and Failure

Natural wetlands are beneficial for a variety of reasons. They convey and store flood waters; are barriers to erosive waves, thereby stabilizing shorelines and stream banks; assimilate natural sediment loads; are essential wildlife habitats; charge ground and surface waters; provide open space and recreational opportunities; are aesthetically pleasing; and protect water quality by removing nutrients and chemical contaminants.

There is general agreement that natural wetlands are important landscape components, providing a variety of ecological, social and aesthetic benefits. Regulatory agencies and scientists have questioned whether created wetlands perform the same functions as their natural counterparts.

In the past decade, research has improved the success rate of wetland restoration and some types of creation projects. But even today, partial or complete failures are widely experienced due to poor planning, design and/or maintenance. Many created wetlands do not persist over time or do not function as they were designed; however, success rates are improving as wetland construction technology advances. Careful siting, monitoring and long-term maintenance are crucial.

The success/failure of restoration and creation also varies with project type. The restoration of emergent marshes, for example, enjoys a relatively high success rate whereas the creation of forested swamps is considerably more difficult and less reliable.

Restoration means reclaiming a degraded wetland to re-establish one or more functions that have been partially or completely lost by such actions as filling or draining. It is the preferred form of mitigation because it typically has the greatest chance of successfully establishing natural wetland functions. It does not, however, necessarily ensure "no net loss" of wetlands.

Due to the uncertainty of wetland creation, the U.S. Environmental Protection Agency and Army Corps of Engineers have adopted a "sequencing" approach to wetland regulation under the Clean Water Act, by which applicants must first demonstrate there is no practicable alternative to the proposed development that would be less damaging to the aquatic ecosystem. If impacts are proven to be unavoidable, applicants must then demonstrate that they have been minimized. Unavoidable impacts that cannot be further minimized must be mitigated by restoring or creating new wetlands. The "enhancement" of existing wetlands is, for the most part, an unacceptable form of mitigation since it clearly does not fulfill "no net loss."

B. Using Created Wetlands As Water Filters

When multiple functions need not be replicated and land is available, constructed wetlands can effectively treat wastewater. In Arcata, California, municipal effluent is largely treated by created wetlands. When Arcatans "flush," gravity takes their wastewater to a conventional treatment plant at the edge of Humboldt Bay, where it is screened and solids settle out. The effluent is then piped to 50 acres of oxidation ponds, where algae remove more waste and solids. Next, the wastewater flows into two 2.5-acre marshes planted with bulrush and cattail, where the sewage effluent is "polished." Finally, it flows into 45 acres of marsh constructed by the city and California Coastal Conservancy to help restore fish, shellfish, waterfowl, and other wildlife to the area. By the time it flows into the Humboldt Bay, the effluent is cleaner than the bay water itself.

Creation means constructing a new wetland, usually by flooding or excavating lands that were not previously occupied by a wetland. It offers the benefit of maintaining no-net-loss of wetland acreage, but not necessarily wetland functions. Wetlands created for a single purpose can be very effective for that use.

Pollutants entering natural wetlands are "treated" by a variety of physical, chemical and biological processes. These processes modify dissolved and particulate substances from "point" and "nonpoint" sources of pollution by settling, filtration, absorption (attaching to soil particles), volatilization, precipitation, complexing, microbial modification, and plant uptake.

Suspended solids, including sediment particles, have a strong tendency to adsorb pathogenic microbial organisms, organics, hydrocarbons, heavy metals and nutrients. Filtration, precipitation and complexing depend on the hydraulic resistance of wetland plants and the nature and chemistry of wetland soils. Increased ponding time increases the length of time that water is in contact with wetland plants and soils and adds treatment via oxidation and volatilization of certain substances, especially metals.

Microorganisms attached to plants, rocks and sand in water bodies modify petroleum products, metals, pathogens and nutrients, causing precipitation of some pollutants and recycling and settling-out of others. A dense stand of wetland plants is most effective at pollutant removal because it provides a large surface area for microbial attachment. And the diffused loss of oxygen from plant roots creates an oxygen-rich environment for microorganisms in otherwise saturated soil. The uptake of nutrients, metals and organic substances by plants permanently removes some pollutants and nutrients and temporarily binds others. The decomposition of herbaceous plants releases many compounds back into the water column after the growing season. Therefore, sedimentation and subsequent microbial modification within the soil profile provide the most effective and permanent pollutant removal mechanisms.

Urban stormwater runoff has been identified as a principle factor in the degradation of the Chesapeake and San Francisco bays and Long Island Sound. Created wetlands used to treat municipal and mine wastewater in the Chesapeake Bay area have successfully removed 80 percent to 90 percent of the nutrients and metallic ions. But treating urban stormwater runoff with created wetlands is not always successful. Unlike discharges of municipal and agricultural wastewater, urban stormwater has widely fluctuating flows with substantial variability in the types and concentrations of pollutants. Stormwater runoff from the first half-inch of rainfall may carry about 90 percent of the pollutants generated during a storm. This rapid influx of highly contaminated stormwater can "shock load" water treatment systems and water resources, such as streams, ponds, lakes, and wetlands. In addition, stormwater runoff often contains greater quantities of sediments and hydrocarbons and, occasionally, heavy metals; nutrient content, however, is often comparable to secondarily treated municipal wastewater.

For surface runoff, the most effective constructed wetland treatment systems include a combination of retention pond, wet meadow, and emergent marsh. Before these created wetlands are designed, however, the objective(s) of the project and the treatment needed should be determined.

The most effective plants for treating stormwater runoff have high oxygen transfer efficiencies; deep, uniform and dense root masses; low bioaccumulation potential; and high tolerance for local environmental conditions. Created wetlands designed for nonpoint source pollution treatment often consist of combinations of cattails, reeds, bulrush, rush, arrowhead, burreed, and/or sedges.

C. Stormwater Wetlands

Definition: Conventional stormwater wetlands are shallow pools that create growing conditions suitable for the growth of marsh plants. These stormwater wetlands are designed to maximize pollutant removal through wetland uptake, retention and settling. Stormwater wetlands are constructed systems and typically are not located within delineated natural wetlands. In addition, stormwater wetlands differ from artificial wetlands created to comply with mitigation requirements in that they do not replicate all the ecological functions of natural wetlands.

Enhanced stormwater wetlands are designed for more effective pollutant removal and species diversity. They also include design elements such as a forebay, complex microtopography, and pondscaping with multiple species of wetland trees, shrubs and plants.

Pollutant Removal Capability: In general, conventional stormwater wetlands have a high pollutant removal capability that is generally comparable to that of conventional wet ponds. Removal of sediment and some nutrients and pollutants may be greater in well designed stormwater wetlands, but phosphorus removal is more variable.

Longevity: Well-designed conventional stormwater wetlands should function for many years, but very few stormwater wetlands are yet ten years old.

Feasibility: Enhanced stormwater wetlands can be applied to most development situations where sufficient baseflow is available to maintain water elevations.

Environmental Concerns: If located improperly, the construction of stormwater wetlands may impact existing forests and natural wetlands; shallow wetlands can also contribute to downstream warming.

Environmental Benefits: With careful design and buffers, enhanced stormwater wetlands can create unique and valuable habitat for waterfowl and other wildlife in an urban setting.

Costs: Construction costs for stormwater wetlands have not been systematically analyzed, but are expected to be marginally higher than wet ponds. Maintenance costs may average three to five percent of construction costs annually.

Adaptability: Enhanced stormwater wetlands can be adapted for most regions of the country that are not excessively arid.

Maintenance Burden: Stormwater wetlands require greater maintenance in the first three years of their life. Thereafter, their management demands are usually similar to other wetland systems.

Usefulness as a Coastal Urban NPS Management Practice: Stormwater wetlands can be beneficial and have great utility in coastal areas throughout most of the United States; therefore, their use in that environment should be encouraged.

Pollutant Removal Mechanisms: Wetlands remove nutrients and pollutants through gravitational settling, wetland plant uptake, adsorption, physical filtration and microbial decomposition. The degree of pollutant removal is a function of aquatic treatment volume, surface area to volume ratio, and the ratio of wetland surface area to watershed area.

Review of Monitoring Studies: Performance studies of conventional natural and constructed wetlands have been conducted. Removal rates are generally comparable to those reported for conventional wet ponds of similar treatment volume; however, sediment removal rates are often slightly higher and nutrient removal rates are somewhat lower. Some cases of negative removal for ammonia and orthophosphorus were reported. Overall performance is greatest during the growing season and lowest during the winter months.

Contributing Watershed Area: Stormwater wetlands can be used in watersheds as small as five acres.

Presence of Baseflow: To maintain a constant water level, it is often necessary to have a reliable dry-weather base flow to the wetland or groundwater supply.

Permeable Soils: It is difficult to establish wetlands on sites with sandy soils, high soil infiltration rates or high summer evapotranspiration rates.

Available Space: Because of their shallow depths, stormwater wetlands can consume two or three times the site area compared to other stormwater quality enhancement options (in some cases, as much as five percent of total site area). The land requirements of stormwater wetlands can be sharply reduced by partially substituting vertical extended detention storage for horizontal wetland storage.

Use in Ultra-Urban Areas: The use of these areas is limited due to space constraints. However, pollutant removal can be obtained by modifying existing degraded urban wetlands for stormwater control.

Retrofit Capability: The addition of wetland features to older dry stormwater basins is an effective retrofit technique. Many retrofits utilize a combination of extended detention, wetlands and a permanent pool (retention).

Stormwater Management Capability: In most cases, stormwater detention can be provided in stormwater (constructed) wetlands.

Design: Typically, design costs for constructed (stormwater) wetland systems are slightly higher than for other stormwater management systems due to the need for environmental analyses of the proposed wetland site and the need for specialized planting techniques.

Construction: Very little systematic cost data is available for the construction of stormwater wetlands. The prevailing viewpoint is that stormwater wetland construction costs exceed those of wet (retention) ponds due to the more complex grading and wetland planting costs. Also, stormwater wetlands may require more space than other stormwater management systems, thereby driving up land acquisition costs.

Maintenance: No reliable maintenance cost data is available. It has been assumed that maintenance costs are comparable to those of other stormwater management systems over the long term. However, costs may well be higher in the first few years after construction due to difficulties encountered in wetland establishment and the possible need for reinforcement plantings.

Stormwater wetlands are no longer an experimental technology. They have been proven to be effective and provide moderate to high levels of pollutant removal throughout the year. Stormwater wetland

designs are numerous, however, and research needs to be done on the optimal combination of wetlands, extended detention and permanent pool storage.

Other uncertainties include:

- uptake of metals by wetland biota
- ability to maintain wetland target species over the long term
- whether the annual plant dieback exports a pulse of nutrients from the system
- the degree to which removal rates are reduced during the non-growing season
- the potential value of annual plant harvesting to increase removal rates

STREAM RESTORATION

A. Vegetative Streambank Stabilization

Eroding stream and shore banks have a detrimental impact on water quality because of the sediment that is discharged from the eroded banks and because eroded banks usually do not have any or enough stabilizing vegetation that also will act to filter out nutrients and contaminants and keep the stream cool by shading it from excessive sunlight. Although structural and non-structural methods can be used to stabilize eroding stream and shore banks, from a water quality protection standpoint the best solutions are often those that focus on non-structural methods. Some of these methods are explained below.

- **Geo-textiles:** Longitudinal geo-textiles are shaped like a boom or log (under the trade name FiberSchine) and are made of natural fibers, such as those from coconut trees, which have been compressed and stuffed into netting. Seeds from wetland vegetation may be planted in the boom or log, which is then installed along stream, pond and lake banks and backfilled with soil. The vegetation will become established long before the fibers decay. The geo-textiles also may be shaped like a fibrous mesh, blanket or plugs. The trade names of some of these are Fiber-Textiles, Fiber-Pallet, and Fiber-Plug, respectively.
- **Live staking:** Live, rootable vegetative cuttings are inserted and tamped into the ground perpendicular to the slope. Most willow (*Salix* sp.) species root rapidly.
- **Live fascine:** Long bundles of live branch cuttings are placed in shallow trenches dug on the contour of the slope. They are held by stout dead stakes driven through the fascines and stout live stakes inserted directly below the bundles. The fascines are then almost covered by moist earth and mulch is placed between rows.
- **Brush layering:** Live branch cuttings are placed on small benches two to three feet wide, excavated at a slight tilt into the slope. Brush-layered branches serve as reinforcing units, retarding runoff and reducing surface erosion, aiding seed germination and natural regeneration.
- **Branch packing:** Alternating layers of live branch cuttings and compacting backfill may be used to repair small localized slumps, holes in slopes, and gullies.
- **Live cribwall:** A hollow, box-like interlocking arrangement of untreated log or timber members is filled with suitable backfill material and layers of live branch cuttings. The cuttings root inside the crib structure and extend into the slope, gradually taking over the structural functions of the wood members.
- **Vegetated rock gabions:** Rectangular containers of triple twisted, hexagonal steel mesh are placed in position, wired to adjoining gabions, filled with stones, then folded shut and wired at the ends and sides. Live branches placed on each layer between the rock-filled baskets will take root inside the gabion baskets and in the soil behind the structures, consolidating the structure and, in time, binding it to the slope.
- **Vegetated rock wall:** A combination of rock and live branch cuttings that differ from conventional retaining structures in that they are placed against relatively undisturbed earth and are not intended to resist large lateral earth pressures.
- **Joint planting:** Live cuttings are tamped into soil between open spaces in rocks that have been previously placed on a slope.

B. Stream Channel Improvements

- ***Remove Channel Lining/Establish Natural Channel*** - Structural modification impacts on the natural behavior of a stream; it prohibits the system from developing a natural pattern on the landscape. Modification usually occurs in the form of channel straightening, allowing for faster means with which to convey quantities of water. While this may be beneficial in some instances for flood control, water quality protection dictates the importance of slowing the velocity of water and allowing pollutants to settle or filter out of the water column.

- ***Storm Drain Retrofit*** - Storm drain outlets are one source of stream pollution. Some outlets contribute to channel erosion, channel scour and sedimentation. To ameliorate these conditions, it is recommended that repair and maintenance practices be implemented. These practices include filter screens, velocity reduction devices, backfilling, and revegetation of damaged stream banks.

C. Urban Housekeeping Practices

- ***Grass Type and Mow Height*** - The type of lawn management practices, such as mowing height, are the most important factors when considering water quality benefits from a grass buffer. To improve a stream's riparian buffer for water quality purposes, it is best to allow grassed areas to grow to a more substantial height (increasing filtering and attenuation capacity).

- ***Street Sweeping*** - Streams receive a large amount of sediment, not only from eroding stream banks but from stormwater runoff as well. Establishing a street sweeping program or revising existing street sweeping schedules will assist in reducing the amount of sediment entering the stream channel by means of stormwater runoff. To be effective, street sweeping should be conducted once per week, especially during winter and spring months.