# NATURAL WETLANDS AND URBAN STORMWATER: POTENTIAL IMPACTS AND MANAGEMENT

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# CONTENTS

Page

Tables.........v
Figures.........vii
Acknowledgments.........ix

1. Introduction.........1

Background.........3

Purpose.........4

2. Wetland Characteristics.........7

Hydrology.........7
Water Quality/Benthic Processes.........9
Biologic/Habitat Functions.........11
Unresolved Issues.........12

3. Stormwater

Changes........................................................................................................... 31
Wetland Soil Changes..........................................................................................................33
Biologic/Habitat Impacts...................................................................................................35
Regional Differences..........................................................................................................38
Impoundments ..............................................................................................................39
Unresolved Issues............................................................................................................49
Unresolved Impoundment Issues..............................................................................50

6. Stormwater Management Practices and Natural Wetlands.................................................................51
Federal and State Stormwater Management Programs.................................................................51
Control of Adverse Impacts..........................................................................................52

Conclusions...........................................................................................................................57
Unresolved Issues............................................................................................................57

7. Summary..............................................................................................................................59
Wetland Functions........................................................................................................... 59
Impacts of Stormwater Discharges.................................................................................59
Management of Stormwater Discharges.......................................................................60

Literature Cited.........................................................................................................................61
Glossary.............................................................................................................................69

# TABLES

Table Page

1. Wetland Types.......... 8

2. Examples of Pollutant Characteristics Found in Stormwater Runoff From Various Land Uses in the Great Lakes Region..........14

3. Ranges in Pollutant Concentrations Found in Urban Runoff..........16

4. Sources of Urban Runoff Pollutants..........16

## FIGURES

Figure Page

1. Approximate geographic areas for SCS rainfall distributions...................................................... .20

2. Hourly fraction of total rainfall within a 24-hour period for each rainfall distribution type......... 20

3. Major climatic regions of North America......................................................................................... 21

4.

The U.S. Environmental Protection Agency (EPA) is in the process of developing and implementing programs to reduce pollutants in urban runoff and stormwater discharges. The protection of natural drainage systems, including wetlands, is an important part of these efforts. The need for a more complete understanding of the effects of stormwater impacts on wetlands has been recognized (Newton, 1989; Stockdale, 1991).

A draft of this issue paper was prepared to focus discussion on these and other related issues at an EPA-sponsored Wetlands and Stormwater Workshop held in Clearwater, Florida, in January 1992. The purpose of the workshop was to investigate and explore various issues, options, and opinions related to the protection of natural wetlands that receive stormwater and urban runoff. The focus of workshop discussions was not on methods for assessing or improving the capacity of wetlands to control stormwater discharges, but on what is known and not known concerning the impacts to natural wetlands from urban stormwater discharges and the opportunities for protecting natural wetlands that receive urban stormwater. The major themes discussed at the workshop include the following:

- Wetlands serve important water quality improvement functions within the landscape, and these functions should be factored into stormwater management strategies.

- Wetlands, because of their unique position in the landscape, naturally receive stormwater. However, when considering diversion of flows to a wetland (either from stormwater sources or non-stormwater sources), it is important to consider that wetlands have a limited capacity for handling increased flows or additional pollutant loadings.

- There was a general recognition that wetlands in urban areas are dramatically altered by uncontrolled runoff, either through natural drainage to those systems or through direct discharge to wetlands. Stormwater management techniques (best management practices, or BMPs), specifically designed to mitigate these impacts, may offset some of the impacts of increased volumes and velocities of runoff that cause changes to wetlands.

- At least 19 potential impacts to wetlands (including changes to the physical, chemical, and biological characteristics of wetlands) were identified by the workshop particpants as being associated with the changes in the hydrology of the wetland system and increases in pollutant loads, or modifications associated with some stormwater management practices.

- There is a great deal of variability in site conditions, as well as regional variability in stormwater characteristics, climate conditions, urban development patterns, soil types, and wetland types that will make the development of nationally prescribed BMPs for protecting wetlands from stormwater impacts difficult.

urban areas may be an integral part of the flow patterns of a wetland (particularly in arid regions). For example, strict restrictions on

## BACKGROUND

Urbanization dramatically alters the natural hydrologic cycle. As urban structures such as roads and buildings are built, the amount of impervious area within a watershed increases. Increases in impervious area increase the volume and rate of runoff, while decreasing groundwater recharge. Urbanization also increases the type and amount of pollutants in surface runoff.

Uncontrolled urban runoff can have adverse impacts on urban wetlands. The dramatic increases in peak flow rates can cause erosion and channelization in the wetlands, which ultimately adversely impact the ability of the wetland to support aquatic habitat. Reductions in groundwater recharge within a watershed can reduce separate storm sewer systems are to effectively prohibit nonstormwater discharges to separate storm sewers and require municipalities to reduce the discharge of pollutants in stormwater to the maximum extent practicable.

EPA issued NPDES permit application requirements for discharges from municipal separate storm sewer systems serving a population of 100,000 or more on November 16, 1990. The municipal component of the regulations focuses on requiring affected municipalities to develop municipal stormwater management programs to reduce pollutants in stormwater and protect receiving waters.

The November 16, 1990, regulations also addressed which types of facilities would be required to obtain NPDES permit coverage for stormwater discharges associated with industrial activity and specified permit application requirements for these discharges.

Section 319 of the CWA amendments requires States to identify waters that, without further action to control nonpoint sources, cannot be expected to attain the water quality standards or goals of the Act. States were also to submit programs for management of nonpoint source pollution.

## PURPOSE

The Wetlands and Stormwater Workshop was conducted to investigate the status of the science regarding the impacts and potential for use of natural wetlands for the storage and treatment of stormwater. To this end, EPA formed a panel of wetland scientists, engineers, and environmental managers to

- Status of the science regarding the treatment of urban stormwater;
- Chemical and physical characteristics of urban stormwater;
- Hydrologic, chemical, and biological impacts of stormwater discharges to natural wetlands;
- Watershed management practices related to stormwater discharges to natural wetlands;
- Regional and resource-related concerns associated with stormwater discharges to wetlands; and
- Programmatic issues and opportunities for implementing sound practices.

The purposes of the workshop were to:

- Investigate the potential impacts on natural wetlands used for urban stormwater control;
- Provide a forum for discussion of topics of concern;
- Form a general agreement as to the state of scientific information; and
- Develop a sound scientific and technical base to derive government policy concerning the use of natural wetlands for urban stormwater control.

A draft of this issue paper was originally developed to provide a base for discussion and to support deliberations at the Wetlands and Stormwater Workshop held in January 1992 in Clearwater, Florida. Chapter 2 of this paper presents a summary of the characteristics and functions of natural wetlands most likely to be impacted by stormwater discharges. An understanding of wetland functions is necessary to be able to predict and measure impacts resulting from stormwater discharges. The hydrologic and chemical characteristics of urban stormwater are summarized in Chapter 3, with a focus on urban development activities that affect the quantity and quality of

# 2. WETLAND CHARACTERISTICS

For the purpose of this paper, wetlands are defined as "those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (40 CFR 230.3). This definition is used by EPA and the U.S. Army Corps of Engineers (Corps) in implementing section 404 of the Clean Water Act. Table 1 briefly describes major freshwater and coastal wetland systems.

Wetlands are subject to increased attention relative to receiving stormwater runoff because of their inherent water storage and water quality improvement capabilities. The role of wetlands as storage areas for stormwater discharges was investigated by EPA (1985a) and Reinelt and Horner (1990), while Richardson (1989) and EPA (1983) documented the role of wetlands in water quality processes. The value of natural wetlands, however, extends beyond their water storage and water quality functions to include food chain support, erosion control, groundwater recharge/discharge, and habitat functions. An understanding of these functions is necessary when contemplating the use of natural wetlands to store and treat urban stormwater discharges in order to predict and measure potential impacts on wetland functions. The potential impacts of urban stormwater on natural wetlands are discussed in Chapter 5.

## HYDROLOGY

Hydrology is probably the most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink, 1986). Precipitation, surface water inflow and outflow, groundwater exchange, and evapotranspiration are the major factors influencing the hydrology of most wetlands. The balance of inflows and outflows of water through a wetland defines the water budget and determines the amount of water stored within the wetland. A wetland experiences natural water level fluctuations (WLFs) that are closely associated with the wetland's morphology and the basin's hydrologic regime (Stockdale, 1991). WLFs are also determined by specific factors including wetland-to-watershed area ratios, level of watershed development, outlet conditions, and soils (Reinelt and Horner, 1990). Changes in activities within the watershed (e.g., urbanization) will affect these natural WLFs.

## Table 1. Wetland Types

### NONTIDAL FRESHWATER

*Lacustrine* - Associated with bodies of water greater than 2 m in depth, or less than 8 ha in area, or less than 30 percent covered by emergent plants.

*Riparian* - Associated with flowing water systems. For example, bottomland wetlands are lowlands found along streams and rivers, usually on alluvial floodplains that are periodically flooded. These are often flooded and termed bottomland hardwood forests.

*Palustrine* - Do not have channelized flow and either are not associated with bodies of water or form the headwaters of streams. These wetlands include the following:

*Marsh* - A frequently or continually inundated wetland generally characterized by emergent, soft-stemmed herbaceous vegetation adapted to saturated soil conditions.

*Swamp* - Wetland dominated by woody vegetation.

*Bog* - A peat-accumulating wetland that has no significant inflows and outflows and supports acidophilic mosses, especially sphagnum.

*Fen*- A peat-accumulating wetland that receives some drainage from surrounding mineral soil and usually supports marshlike vegetation.

*Wet prairie* -Similar to a marsh.

*Wet meadow* - Grassland with waterlogged soil near the surface but without standing water for most of the year.

*Pothole* - Shallow marsh-like pond, particularly as found in the Dakotas

*Playa* - Term used in southwest United States for marshlike ponds similar to potholes, but with different geologic origin.

### COASTAL

*Tidal salt marshes* - Found throughout the world along protected coastlines in themiddle and high latitudes. In the United States, these wetlands are often dominated by *Spartina* and Juncus grasses. Plants and animals in these systems are adapted to the stresses of salinity, periodic inundation, and extremes in temperature.

*Tidal freshwater marshes* - Found inland from tidal salt marshes, but still experiencetidal effects. These marshes are an intermediate in the continuum from coastal salt marshes to freshwater marshes.

*Mangrove wetlands* - Found in subtropical and tropical regions. These wetlands are dominated by salt-tolerant red mangrove or black mangrove trees.

SOURCE: Mitsch and Gosselink, 1986.

The time of year and the depth, frequency, and duration of inundation and soil saturation (wetland hydroperiod) are key factors in determining the impacts of water-level changes in wetlands (Stockdale, 1991). Within the wetland, the wetland hydroperiod influences the biochemistry of the soils and is a major factor in the natural selection of wetland biota (Reinelt and Horner, 1990). The hydroperiod is unique to each type of wetland, and its relative constancy ensures stability for that wetland. Mitsch and Gosselink (1986) suggest characterizing hydroperiod by the ratio of flood duration divided by flood frequency (i.e., the amount of time a wetland is exposed to excess floodwaters over the average number of times a wetland is flooded in a given period). Changes in the hydroperiod can affect such processes as nutrient transformation and availability (Hammer, 1992); responses of biota, including both enrichment of species and degradation of species diversity with succession to a different vegetative community, (Zimmerman, 1987); and amphibian egg and larval development (Richter et al., 1991). Changes in the hydroperiod can be measured by the average change in water level occurring in the wetland (Azous, 1991).

Seasonality is also a characteristic of hydroperiod. Some wetlands have water year-round, while others may become dry during the summer period. Reduced groundwater base flows are frequently cited as a consequence of urbanization and may result in extending the length of the dry period in wetlands, with seasonally affected groundwater sources potentially impacting the life cycles of species dependent on the water column (Azous, 1991).

A major hydrologic feature of coastal salt marshes and freshwater tidal marshes is the periodic tidal inundation. The tides act as a stress by causing submergence, saline soils, and soil anaerobiosis. The tides act as a subsidy by removing excess salts, reestablishing aerobic conditions, and providing nutrients (Mitsch and Gosselink, 1986). The periodic tidal inundations influence the species that occur in the wetland because of the water depth and duration of flooding. Salinity is also a major factor in influencing what vegetation is found in the wetland, with a salinity gradient generally high in the low marsh and decreasing as the elevation increases. If the salinity in the adjacent waterbody is less than 5 parts per thousand (ppt), salt marsh vegetation is replaced by freshwater plants (Mitsch and Gosselink, 1986).

# WATER QUALITY/BENTHIC PROCESSES

An important function of wetlands is their role in changes that occur in water quality.

change the soils from an aerobic to an anaerobic system, with many resultant chemical (reduction-oxidation) transformations in the wetland. The chemical transformations are governed by pH and redox potentials (Eh) and determine the state of the nutrient, mineral, or heavy metal entering the water column in the wetland or infiltrating the groundwater. The relationship between Eh and pH manifests itself in chemical speciation; e.g., the predicted pH level necessary to precipitate iron or manganese is much higher at low Eh levels than at higher Eh levels (Faulkner and Richardson, 1989).

Nitrogen and phosphorus speciation are two of the most important chemical transformations occurring in wetlands. Of the many elements necessary to sustain biotic production in wetlands, nitrogen presents special research challenges because of its chemical versatility. This versatility is expressed in the various valence states nitrogen can occupy (-3 to +5), in the intricate array of biotic and abiotic transformations in which nitrogen participates, and by the fact that, like few other elements, nitrogen occurs naturally in soluble and gaseous phases (Bowden, 1987). In a wetland, only a fraction of available nitrogen is removed by plants, with the most effective removal by nitrification/denitrification (Knight et al., 1986). A limiting factor for nitrogen removal is anoxia. In aerobic substrates ammonia is oxidized to nitrate by nitrifying bacteria. Nitrates (NO3) are then converted to free nitrogen in the anoxic zones by denitrifying bacteria.

Phosphorus removal in wetlands systems occurs from adsorption, absorption, complexation, precipitation, and burial. Removal rates are highest in systems where a significant clay content is present (Watson et al., 1988). Another factor affecting phosphorus removal is the presence of iron, aluminum, or calcium. For example, Richardson (1985) found that the phosphorus adsorption capacity of a wetland soil can reptile, amphibian, and fish species. Some aquatic organisms may use wetlands seasonally as a spawning ground and nursery for their young, spending most of their adult lives in deeper waters. Amphibians, reptiles, and invertebrates usually undergo an aquatic phase that requires water for breeding, egg development, and larval growth. Some reptiles and amphibians are able to adapt to fluctuating water levels (Mitsch and Gosselink, 1986), whereas others may experience changes in breeding patterns and species composition due to water level fluctuations (Azous, 1991). Wetlands are also used daily by birds and terrestrial animals for diurnal and nocturnal food foraging. Many birds that inhabit both terrestrial and wetland habitats are frequently found in the highest numbers in the diverse, productive habitats of wetlands (NWTC, 1979).

The wetland vegetative community is determined by climate and wetland hydrology. Wetland plant species are established based on their water regime requirements and

- A greater understanding of habitat processes and functions and how changes in these functions affect the support of living organisms is needed.

- New and improved methods are needed to measure and assess the habitat functions of wetlands.

## 3. STORMWATER CHARACTERISTICS

As human activities alter the watershed landscape, adverse impacts to receiving waters may result from changes in the quality and quantity of stormwater runoff. Unmanaged storm surges increase discharges during runoff-producing storm events. These discharges result in a predictable change of waters flowing to those receiving waters. If left unmanaged, the hydraulic impacts associated with the increased water volumes may be several orders of magnitude higher than the impact of the undisturbed watershed. In addition to causing runoff volume impacts, stormwater can also be a major source of nonpoint source pollution in many watersheds.

Six main source activities contribute to surface water runoff pollution:

- Agriculture,
- Silviculture,
- Mining,
- Construction,
- Urban activities, and
- Atmospheric deposition.

The first five are the traditional sources; the sixth, atmospheric deposition, has only recently been recognized as a major contributor of some types of nonpoint source pollution in certain regions of the country. The type and quality of pollutants carried by storm runoff, commonly resulting in nonpoint source pollution of receiving waters, are highly variable (USEPA, 1984). The pollutant characteristics of stormwater runoff are largely based on land use characteristics (as illustrated in Table 2) and vary with the duration and the intensity of rainfall events (Metropolitan Washington Council of Governments, 1980). Table 2 illustrates the variability of pollutant loads associated with stormwater runoff. For example, Table 2 shows that loads of suspended sediment vary considerably within a land use and between land uses. Pollutant characteristics from stormwater runoff also vary regionally.

The remainder of this chapter focuses specifically on the chemical and hydrologic characteristics of urban stormwater. Knowledge of these characteristics is necessary to understand and predict the potential impacts such discharges may have on natural wetlands. The potential impacts of urban stormwater discharges on natural wetlands are discussed in Chapter 5 of this document.

**Table 2. Examples of Pollutant Characteristics Found in Stormwater Runoff From Various Land Uses in the Great Lakes Region**

| Land Use | Suspended Sediment (kg/ha-yr) | Total Nitrogen (kg/ha-yr) | Total Phosphorus (kg/ha-yr) | Lead (kg/ha-yr) |
|---|---|---|---|---|
| General Agriculture | 5-8000 | 0.8-75 | 0.1-9 | 0.003-0.09 |
| Cropland | 30-7500 | 6-60 | 0.3-7 | 0.006-0.007 |
| Improved Pasture | 50-90 | 5-15 | 0.1-0.6 | 0.005-0.02 |
| Forested/Wooded | 2-900 | 1-8 | 0.03-0.7 | 0.01-0.05 |
| Idle/Perennial | 9-900 | 0.6-7 | 0.03-0.7 | 0.01-0.05 |
| General Urban | 300-2500 | 8-10 | 0.5-4 | 0.2-0.6 |
| Residential | 900-4000 | 6-9 | 0.6-1 | 0.08a |
| Commercial | 75-1000 | 3-12 | 0.09-0.9 | 0.3-1.0 |
| Industrial | 750-2000 | 3-13 | 0.9-6 | -b |
| Developing Urban | >>10,000[a] | 90[a] | >10[a] | 3.0-7.0 |

[A] Only one value reported.
[B] Not measured
SOURCE : Novotny and Chesters, 1981.

## URBAN ACTIVITIES THAT AFFECT STORMWATER CHARACTERISTICS

Urban runoff quantity and quality are significantly affected by watershed development. Urbanization alters the natural vegetation and natural infiltration characteristics of the watershed, causing runoff from an urban area to have a much higher surface flow component, a much smaller interflow component, and a somewhat reduced baseflow component. Urbanization also can create water quality problems because activities associated with urbanization create sources of pollutants for surface runoff. Thus urbanization tends to increase runoff and pollutant loadings to the receiving waterbody (Woodward-Clyde Consultants, 1990).

The following sections describe the chemical and hydrologic characteristics of urban stormwater and the urban/development activities that affect those characteristics.

## CHEMICAL CHARACTERISTICS

One significant effect of urbanization is to increase pollutant runoff loads over predevelopment levels. During a storm event, land surfaces, including impervious surfaces, are washed clean by the rainfall and the resulting runoff creates an increased loading of pollutants to receiving streams (Livingston, 1989). Pollutant concentrations in urban runoff vary considerably, both during the course of a storm event and from event to event at a given site, from site to site within a given urban area, and from one urban area to another across the country. This variability is the result of variations in rainfall characteristics, differing watershed features that affect runoff quantity and quality, and variability in urban activities (Woodward-Clyde Consultants, 1990). Table 3 presents ranges of urban runoff pollutant concentratons based on results of the Nationwide Urban Runoff Program (NURP) as reported in Woodward-Clyde Consultants (1990). Values reported in Table 3 represent the mean of event mean concentration pollutant values for the median, 10th percentile, and 90th percentile sites in the NURP data. Potential sources of urban runoff pollutants are presented in Table 4. The principal types of pollutants found in urban runoff from these various sources include:

- Sediment
- Oxygen-demanding substances (organic matter)
- Nutrients
    - phosphorus
    - nitrogen
- Heavy metals
    - copper
    - lead
    - zinc
    - others

- PAHs
- others

## Table 3. Ranges in Pollutant Concentrations Found in Urban Runoff

| Constituent | Mean Concentration in Runoff<br>10th Percentile Urban Site | Median Urban Site | 90th Percentile Urban Site |
|---|---|---|---|
| Total Suspended Solids (mg/L) | 35 | 125 | 390 |
| BOD (mg/L) | 6.5 | 12 | 20 |
| COD (mg/L) | 40 | 80 | 175 |
| Total Phosphorus (mg/L) | 0.18 | 0.41 | 0.93 |
| Soluble Phosphorus (mg/L) | 0.10 | 0.15 | 0.25 |
| Total Kjedahl Nitrogen (mg/L) | 0.95 | 2.00 | 4.45 |
| Nitrate-Nitrogen (mg/L) | 0.40 | 0.90 | 2.20 |
| Total Copper | 15 | 40 | 120 |
| Total Lead | 60 | 165 | 465 |
| Total Zinc | 80 | 210 | 540 |

SOURCE: Woodward-Clyde Consultants, 1990.<R>

**Table 4. Sources of Urban Runoff Pollutants**

| Source | Pollutant of Concern |
|---|---|
| Erosion<br>nutrients,<br>adsorbed | Sediment and attached soil<br>organic matter, and other<br>pollutants. |
| Atmospheric Deposition | Hydrocarbons emitted from automobiles, dust, aromatic hydrocarbons, metals, and other chemicals released from industrial and commercial activities. |
| Construction Materials | Metals from flashing and shingles, gutters and downspouts, galvanized pipes and metal plating, paint, and wood preservatives. |
| Manufactured Products | Heavy metals; halogenated aliphatics; phthalate esthers; PAHs; other volatiles; and pesticides and phenols from automobile use, pesticide use, industrial use, and other uses. |
| Plants and Animals | Plant debris and animal excrement. |
| Nonstormwater Connections | Inadvertent or deliberate discharges of sanitary sewage and industrial wastewater to storm rainage systems. |
| Accidental Spills | Pollutants of concern depend on the nature of the spill. |

SOURCE: Based in part on Woodward-Clyde Consultants, 1990.

The following changes in stream hydrology in a typical, moderately developed watershed were summarized by Schueler (1987):

- Increased peak discharges compared to predevelopment levels (Leopold, 1968; Anderson, 1970);

- Increased volume of storm runoff produced by each storm in comparison to predevelopment conditions;
- Decreased time needed for runoff to reach the stream (Leopold, 1968), particularly if extensive drainage improvements are made;

- Increased frequency and severity of flooding;

- Reduced streamflow during prolonged periods of dry weather due to the reduced level of infiltration in the watershed; and

- Greater runoff velocity during storms, due to the combined effect of higher peak discharges, rapid time of concentration, and the smoother hydraulic surfaces that occur as a result of development.

# 4. REGIONAL DIFFERENCES IN STORMWATER CHARACTERISTICS AND IN WETLAND TYPES

To comprehensively evaluate the impacts and potential for use of natural wetlands for the storage and treatment of urban stormwater runoff, it is essential to understand the regional variations, both in stormwater runoff and in natural wetland types, that exist throughout the Nation. The following sections briefly summarize these differences.

## REGIONAL DIFFERENCES IN STORMWATER CHARACTERISTICS

The characteristics of precipitation events control the timing, volume, and intensity of urban stormwater runoff. The U.S. Department of Agriculture, Soil Conservation Service (SCS) developed dimensionless rainfall distributions using U.S. Weather Bureau data (McCuen, 1989). The distributions are based on generalized rainfall volume-duration-frequency relationships and indicate that there are four geographically distinct rainfall regions in the United States, illustrated in Figure 1. Figure 2 is a dimensionless hydrograph that shows the hourly fraction of total rainfall that falls in a 24-hour period for each rainfall distribution type (Ferguson and Debo, 1990).

*Figure 1. Approximate geographic areas for SCS rainfall distributions (Adapted from McCuen, 1989))

*(Figure 2. Hourly fraction of total rainfall within a 24-hour period for each rainfall distribution type (Ferguson and Debo, 1990))

Climatic variations result in different storm intensities for each rainfall distribution type. Figure 3 illustrates the major climatic regions of North America (Ahrens, 1982) and shows that the four SCS rainfall distribution types have very different climatic regimes. Figure 4 shows the frequency of thunderstorms experienced nationwide, given in days per year when thunderstorms are observed (Ahrens, 1982). It is obvious why Type IA, with 20 percent of the rainfall volume falling during the 8th hour of a 24-hour storm, and Type III, with 55 percent of the rainfall volume falling during the 12th hour of a 24-hour storm, have very different stormwater characteristics. Type IA regions have Maritime and Mediterranean climates with onshore winds producing mild, wet winters with frequent, light precipitation; dry summers; and very few thunderstorms annually. Typical Type IA storms are long, steady periods of relatively light rainfall. Type III regions are coastal areas with a humid subtropical climate, with adequate precipitation throughout the year, cold to mild winters, and hot and humid summers with frequent thundershowers. Typical Type III storms are short, high-intensity rainfall events.

*** - To view the Figures, please call (202) 260-9043 to order a copy.**

*(Figure 3 - Major climatic regions on North America (after Koppen)(AAhrens, 1982))

*(Figure 4 - Average number of days each year on which thunderstorms are observed throughout the United States (Ahrens, 1982))

Seasonality of precipitation, the time of year in which the precipitation falls, is another important factor that must be considered when evaluating stormwater runoff. Water available during the growing season has a different impact from that of water that becomes available when the plants are dormant. Precipitation that falls as snow during the winter months and melts during the spring thaw has a profound effect on local stream levels.

*(Figure 5 - Month-to-month variation of precipitation in the United States (U.S. Weather Bureau (Chow, 1964))

When precipitation intensity and frequency are combined with watershed cover characteristics, the runoff characteristics of a region can be estimated. Runoff estimations are useful for estimating impact to a natural wetland from stormwater. Figure 6 gives average annual runoff in inches for the United States (Chow, 1964).

(Figure 6 - Average annual runnoff in the United States (Chow, 1964))

## REGIONAL DIFFERENCES IN WETLAND TYPES

The United States has a wide range of wetland types that result from the interaction of many separate environmental variables. The characteristics of wetlands derive from and are controlled by two interrelated factors: (1) origin and (2) regional climatic factors.

The origin of a wetland, and the resulting topography, affects and determines critical vegetation are summarized in Table 6.

*** - To view the Figures, please call (202) 260-9043 to order a copy.**

## RELATIONSHIP BETWEEN REGIONAL CHARACTERISTICS OF STORMWATER AND WETLANDS

The relationship between stormwater characteristics and wetland type will influence the degree and character of the impacts to natural wetlands that may result from urban stormwater discharges. The regional differences in stormwater hydrology and wetland types summarized above can play a significant role in determining such impacts. Table 7 presents the wetland types that occur in each of the SCS rainfall distribution areas to illustrate a method of describing the relationship between stormwater characteristics and wetland types. By identifying those regions of the country in which rainfall is characterized by the fraction of rain that falls per hour during a 24-hour period (e.g., rainfall is more or less evenly distributed during a 24-hour period or is characterized by a gradual build-up of rainfall, followed by a brief period of relatively intense rainfall and gradual dissipation) and the wetland types that occur in those regions, storm hydrology can be linked to wetland type. Also, the actual hydroperiod characteristics of natural wetlands depend on specific watershed land use and wetland morphology, soils, and biological nature in addition to regional climate. The effects that regional differences in wetland type and stormwater characteristics may have on impacts on natural wetlands that receive stormwater are briefly discussed in Chapter 5.

*(Figure 7 - Physiographic regions of the United States (Mitsch and Gosselink, 1986)

*** - To view the Figures, please call the EPA Wetlands Hotline @ (1-800-832-7828 to order a copy of manual.**

## Table 5. Locations of Wetland Types in the United States

| Wetland Type | Primary Regions[a] | States |
|---|---|---|
| Inland freshwater marshes | Prairie pothole region: Eastern Highlands (7); Upper Midwest (9); Dakota-Minnesota drift and lake bed flats (8); Central Hills and Plains (10)West Coast: Pacific Mountains (13) | New York and New Jersey to North Dakota and eastern Montana; Washington, Oregon, northern California |
| Bogs | Upper Midwest (9); Gulf-Atlantic Rolling Plain (5); Gulf Coastal Flats (4); and Atlantic Coastal Flats (3) | Wisconsin, Minnesota, Michigan, Maine, Florida, North Carolina Florida, North Carolina |
| Tundra | Central Highland and Basin; Arctic Lowland; and Pacific Mountains | Alaska |
| Wooded swamps | Upper Midwest (9); Gulf Coastal Flats (4); A tlantic Coastal Flats (3); and Lower Mississippi Alluvial Plain(6) | Minnesota, Wisconsin, Michigan, Florida, Georgia, South Carolina, North Carolina, Louisiana |
| Bottom land hardwood | Lower Mississippi Alluvial Plain Atlantic Coastal Flats (3); Gulf-Atlantic Rolling Plain (5); and Gulf Coastal Flats (4) | Louisiana, Mississippi, Arkansas, Missouri, Tennessee, Alabama, Florida, Georgia, South Carolina, , North Carolina, Texas |
| Coastal salt marshes | Atlantic Coastal Zone (1); Gulf Coastal Zone (2); Eastern High-Lands (7); Pacific Mountains(13) | All coastal States, but particularly the Mid-and South Atlantic and Gulf Coast States |
| Mangrove swamps | Gulf Coastal Zone (2) | Florida and Louisiana |
| Tidal freshwater marshes | Atlantic Coastal Zone (1) and Flats(3); Gulf Coastal Zone (2) and Flats (4) | Texas, Louisiana, Mississippi, Alabama, Florida, all of the Atlantic coastal states |

[a] Numbers in parentheses refer to the geographic regions in the United States identified in Figure 7

SOURCE: Adapted from OTA, 1984 and Mitsch and Gosselink, 1986.

**To view Table 6, please call 1-800-832-7828 to order a copy the Natural Wetlands and Urban Stormwater: Potential Impacts and Management maunal.**

### Table 7. Wetlands Present in SCS Type Rainfall Distribution Areas

| SCS Type | Wetland Type | State |
|---|---|---|
| Type I | Tundra | AK, HI |
| | Coastal salt marsh | WA, OR, CA |
| | Tidal freshwater marsh | CA, AK |
| Type IA | Coastal salt marsh | WA, OR, CA, AK |
| | Tidal freshwater marsh | WA, OR, CA |
| Type II | Inland freshwater marsh | NY, PA, OH, MI, IN, WI, IL, MN, |
| | | ND, SD, MT, WA, OR |
| | Bogs | WI, MN, MI, ME, FL, NC |
| | Wooded swamps | MN, WI, MI, FL, GA, SC, NC, |
| LA | Bottomland hardwood | LA, MS, AR, MO, TN, AL, FL, |
| GA, SC, | | NC, TX |
| | Coastal salt marsh | DE, MD, VA |
| | Mangrove swamps | FL |
| | Tidal freshwater marsh | FL, VA, MD, DE |
| Type III | Coastal salt marsh | ME, NH, MA, RI, CT, NY, NJ, |
| NC, SC, | | GA, northern FL, AL, MS, LA, |

# 5. POTENTIAL IMPACTS OF URBAN STORMWATER RUNOFF ON NATURAL WETLANDS

Stormwater runoff has the potential of influencing natural wetlands in four major areas: wetland hydrology, wetland soils, wetland flora and fauna, and wetland water quality. There is little doubt that urban stormwater discharges can affect wetlands; however, the long-term impacts on natural wetlands from urban stormwater discharges are not known at this time. Perturbations to wetland hydrology can cause fluctuations in the character of the ecosystem that are seen as changes in the species composition and richness, primary productivity, organic deposition and flux, and nutrient cycling (Livingston, 1989). Naturally occurring quantities of runoff with seasonal fluctuations are essential for the maintenance of a wetland, and moderate amounts of nutrients and sediment in the runoff can increase a wetland's productivity (Stockdale, 1991). However, excessive stormwater discharge on a continuous basis has the potential to alter wetland hydrology, topography, and the vegetative community (Johnson and Dean, 1987 in Stockdale, 1991). A few investigations that look at the potential impacts to natural wetlands from stormwater discharges have been initiated. Some of these impacts have been identified and others require further investigation. This chapter examines the nature of changes to wetland hydrology, soils, and water quality attributed to stormwater runoff and the perceived effects on the biologic community.

## HDYROLOGIC CHANGES

As a result of urbanization, the quantity and quality of stormwater runoff change due to physical changes occurring in the watershed. The quantity of water entering a wetland as stormwater runoff is dependent on factors such as drainage basin area, imperviousness of the drainage basin, routing of stormwater within the drainage basin, and climate (Lakatos and McNemar, 1987). Increased impervious area in the watershed (from building construction, roadways, and parking lots), removal of trees and vegetation, and soil compaction can increase the quantity of urban stormwater runoff (Schueler, 1987). Water velocity also increases, in general, as the degree of urbanization increases (Viessman et al., 1977). These same activities will potentially cause decreased infiltration of stormwater to groundwater, resulting in decreased base flow.

One basis for determining the impacts to a wetland from stormwater runoff is the wetland's natural hydroperiod. Impacts will also vary depending on the wetland type and size and whether the runoff is intercepted before entering the wetland. Brinson (1988) characterized wetlands, geomorphologically, in three major categories:

- Basin — Wetlands typically in headwater regions that capture drainage from small areas and may receive precipitation as the primary source of water. They are characterized by vertical fluctuations of the water table, a long hydroperiod, low hydrologic energy, and low nutrient levels. Plant communities are usually concentric zones of similar vegetation.

- Riverine — Wetlands that occur throughout the landscape and are primarily affected by water flowing downstream. Riverine wetlands typically have short hydroperiods, high hydrologic energy, and high nutrient levels. Plant communities are usually parallel to the direction of water flow.

- Fringe — Wetlands that are usually located at the base of a drainage basin and next to a large body of water. They generally have a long hydroperiod, high hydrologic energy, and variable nutrient loads. Fringe wetlands are also usually influenced by frequent flushing by bidirectional waterflow. Many fringe wetlands are located in estuarine areas. Zonation of vegetation is usually perpendicular to the direction of water flow.

Although these classifications are very general, Brinson (1988) acknowledges that classification of many wetlands is not clear-cut and the definitions tend to overlap.

Known impacts to wetlands associated with increased storm runoff include change in wetland response time, change in water levels in the wetland, and change in detention time of the wetland. The response time is the time it takes for a wetland’s water depth to begin to rise in response to a storm event occurring in the watershed. The wetland’s water depth will begin to rise sooner as the infiltration capability of the watershed decreases. The greater the amount of runoff entering the wetland soon after the storm event, the greater the water level fluctuation (WLF) (Azous, 1991). On the other hand, the increased runoff at the expense of infiltration may cause local water tables to be reduced along with reducing base flows of local streams (USEPA, 1985). Reduction in groundwater base flows has the potential effect of extending the length of dry periods in wetlands with seasonally affected groundwater sources, potentially impacting the life cycles of the species dependent on the water column (Azous, 1991).

Increased impervious surface areas have the effect of increasing flood peaks during storms and decreasing low flows between storms (Stockdale, 1991). Larger peak flows can result in scoured streambeds as the beds enlarge to accommodate larger flows. Associated impacts include increased sediment loading to bordering vegetated wetlands and reduction of fish spawning habitat (Canning, 1988). In addition to increased flows, urbanization can increase the velocity of the stormwater entering the wetland, which can result in biotic disturbances (Stockdale, 1991). Disrupted flow patterns and channeling can result in decreased pollutant removal efficiencies (Morris et al., 1981), and the changes in velocity will determine deposition as well as eroded areas (USEPA, 1985).

Changes in average water levels or duration or frequency of flooding will also alter species composition of plant and animal communities and distribute pollutants more extensively throughout the wetland (Stockdale, 1991). Cooke (1991) states that species richness is affected by increases in water level fluctuation, with decreased the parameter that exceeds effluent requirements of stormwater runoff. Other authors (ABAG, 1979; Schiffer, 1989) have also reported high percentage removals of suspended solids from stormwater runoff passing through a wetland.

## Table 8. Comparison of Stormwater Runoff Quality

| | SPRING 1975 | | | SUMMER 1975 | | | FALL 1975 | | |
|---|---|---|---|---|---|---|---|---|---|
| Drainage Group | TP (mg/L) | $NH_3$-N (mg/L) | TSS (mg/L) | TP (mg/L) | $NH_3$-NTSS (mg/L) | (mg/L) | TP (mg/)L | $NH_3$N (mg/L) | TSS (mg/L) |
| Undeveloped | 2.2 | 3.33 | 780 | 0.37 | 4.13 | 1200 | 0.30 | 4.33 | 70 |
| Low-Density | 2.4 | 3.87 | 559 | 0.73 | 5.44 | 3800 | 0.42 | 4.97 | 60 |
| Residential Business/ | | | | | | | | | |
| Commercial | 2.0 | 2.85 | 580 | 0.22 | 5.13 | 374 | 0.22 | 4.00 | 68 |
| Urban Roadway | 1.9 | 2.55 | 614 | 0.09 | 2.86 | 200 | 0.25 | 3.81 | 100 |
| Average 2.1 | 3.15 | 633 | 0.35 | 4.39 | 1394 | 0.30 | 4.28 | 75 | |

Note: Above concentrations are based on weighted values calculated from specific runoff events that occurred during the study period.

TP = Total phosphorus
$NH_3$-N = Ammonia nitrogen
TSS =Total suspended solids<R>SOURCE: Hickok et al., 1977.

Chemically, water quality parameters of concern can be broken down into nutrients, metals, and other toxics. Nutrients include phosphorus and nitrogen and are generally linked to eutrophication problems in receiving waters. Metals present in stormwater runoff may include copper, chromium, cadmium, nickel, lead, iron, manganese, and zinc. Other metals may be present depending on the specific activities within the drainage basin feeding the wetland. Miscellaneous toxics that may be present in stormwater runoff include pesticides, hydrocarbons, and organic compounds. Table 9 compares three wetlands used to treat stormwater runoff and gives an indication of the variability of pollutant removal between wetlands. This table shows some of the variability found between different wetlands. For example, phosphorus decreases about 79 percent in the Wayzata wetland, increases about 6 percent in the Palo Alto wetland, and decreases about 87 percent in the Island Lake wetland.

The fate of chemicals entering a wetland is highly variable and depends on many chemical and physical factors (Richardson, 1989). At times, wetlands serve as a sink for pollutants, which are stored in the wetland. Wetlands can also transform pollutants from one form to another. The transformation may be from a desirable to an undesirable state, or the converse can occur. The complex chemical reactions that occur in wetlands change with time. For example, a pollutant being stored in a wetland can become a transformed pollutant that is subsequently exported from the wetland (Richardson, 1989).

Biological changes in water quality for wetlands receiving stormwater runoff typically are reported as changes in the bacteriological quality of the water. Horner (1988) reported that bacterial indicatorn (fecal coliforms and enterococci) within wetlands increased in numbers in more highly urbanized watersheds. The levels reported by Horner (1988) did not exceed water quality standards and were in areas not typically used directly by humans. However, wetlands with elevated bacterial levels that discharge to shellfish areas may be of concern. Reinelt and Horner (1991) found that the water columns in wetlands with a flow-through (more channelized) character in urbanized areas had higher bacterial levels than more quiescent open-water systems. The difference was attributed to settling of sediment, and the adsorbed bacteria, out of the water column in the open-water systems. Reinelt and Horner (1991) compared levels of chlorophyll *a*, an indicator of algal growth, in several wetlands and found that open-water wetland systems had higher levels than those of other systems.

## WETLAND SOIL CHANGES

Physical, chemical, and biological qualities of the soil substrate change in wetlands as

## Table 10. Summary of Mean Soil and Sediment Chemistry Data as a Function of Sampling Location, December 1978 (in mg/kg unless noted)

| Source of<br>Validation | pH | (mmhos/cm) | EC<br>Carbon | Organic<br>TKN | NH3-N | Total-P | P | Available<br>Cu | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| Lateral Positio | | | | | | | | | | |
| Lower Marsh | 4.9 | 21 | 2.0 | 458 | 72 | 605 | 2.7 | 14 | 28 | 23 |
| Middle Marsh | 5.9 | 10 | 2.1 | 372 | 37 | 667 | 7.3 | 14 | 38 | 26 |
| Upper Marsh | 5.7 | 18 | 2.3 | 1,320 | 52 | 700 | 7.4 | 23 | 70 | 25 |
| Vertical Position | | | | | | | | | | |
| 0 - 8 inches | 5.9 | 10 | 2.0 | 1,002 | 39 | 710 | 10.0 | 19 | 48 | 27 |
| 8 -6 inches | 5.5 | 17 | 2.4 | 495 | 70 | 707 | 4.5 | 17 | 56 | 25 |
| 16 - 24 inches | 5.2 | 22 | 2.1 | 670 | 51 | 550 | 2.9 | 15 | 33 | 22 |
| Vegetative Cover | | | | | | | | | | |
| Pickleweed | 4.7 | 25 | 2.0 | 948 | 40 | 719 | 8.7 | 15 | 32 | 23 |
| Salt Bush | 5.1 | 13 | 2.0 | 388 | 30 | 747 | 7.2 | 17 | 41 | 25 |
| Rye Grass | | | | | | | | | | |

Table 11. Distribution of Selected Constituents in Water, Sediments, and Groundwater at the Silver Star Road Study Area

| | Water Column (mg/L) | | | Sediments (mg/kg) | |
|---|---|---|---|---|---|
| Constituent | Pond Inlet | Wetland Inlet | Wetland Outlet | Pond | Wetlands |
| Specific conductance[a] | 145 | 144 | 153 | — | — |
| pH-lab[b] | 7.2 | 7.1 | 6.9 | — | — |
| Ammonia nitrogen | 0.8 | 0.2 | 0.4 | 92 | 14 |
| Nitrogen ammonia plus nitrite | 0.10 | 0.10 | 0.10 | 9 | 6 |
| Phosphorus | 0.06 | 0.10 | 0.08 | 1,100 | 260 |
| Total organic carbon | 15 | 15 | 15 | — | — |
| Cadmium | <0.001[c] | <0.001[c] | <0.002 | <6 | <1 |
| Chromium | <0.003 | <0.001[c] | <0.002 | 20 | 2 |
| Copper | 0.01 | <0.01[c] | <0.01[c] | 49 | 3 |
| Iron | — | — | — | 4,400 | 640 |
| Lead | 0.034 | 0.026 | 0.010 | 620 | 20 |
| Zinc | 0.06 | 0.05 | 0.03 | 250 | 14 |

**[a] Microsiemens per centimeter at 25 °C.**

**[b] pH units.**

**[c] Detection level**

**SOURCE: Schiffer, 1989.**

Biological activity within wetland soils is also subject to change due to changing conditions. The only documented change found in the literature was soil microbial activity. Hickok et al. (1977) examined changes in soil microbial activity due to changes in soil moisture conditions and found microbial activity to be directly related to increases in soil moisture.

## BIOLOGIC/HABITAT IMPACTS

The impacts of urbanization and stormwater discharge on wetland systems are interactive and not clearly understood at this time. The changes in hydrology, Increasing flood frequency or water level fluctuations could cause the mortality of certain plant species while favoring the productivity of others. Stockdale (1991) in his literature review states that the character of wetland vegetation and riparian areas is primarily governed by the flooding regime (Thibodeau and Nickerson, 1985), with periodic inundation promoting richer and more abundant species composition than either constant dry or constant flooded conditions (Conner et al., 1981; Gomez and Day, 1982). Determining plant responses to these stresses is difficult because direct responses (physical damage) and indirect responses (physiological responses to direct impacts) are numerous and often simultaneous (Koslowski, 1984 in Azous, 1991).

Plant species are generally specific in their requirements for germination, and many are sensitive to flooding effects once established (Niering, 1989 in Azous, 1991). Mature trees may survive inundation, whereas the same water level fluctuations may retard or limit the establishment of seedlings and saplings (Stockdale, 1991). Newton (1989) and Stockdale (1991) list the relative flood tolerance of woody plants. Little information is available on the effects of hydroperiod on emergent plants, though Kadlec (1962) found that several species of emergent plants were tolerant of lengthy dry periods (Azous, 1991). Because the tolerance to flooding, intermittent and prolonged, varies so widely among and within plant species, it is hard to extrapolate from the literature what the impact on a certain plant species within a community will be. Some information, however, is known about hydroperiod impacts on individual species (Stockdale, 1991):

- *Typha* spp.- survive well under fluctuating conditions.
- *Phalaris arundinaceae*— has a wide tolerance to WLF, but does not survive long periods of inundation during the growing season.
- *Spiraea douglasii*- highly tolerant of fluctuating groundwater tables.
- *Carex* spp.— highly specific in hydrologic preferences.

Horner (1988) found that emergent zones of palustrine wetlands receiving urban runoff in the Pacific Northwest were dominated by an opportunistic exotic grass *(Phalaris arundinaceae)* while unimpacted wetland plant communities were composed of a more diverse group of species. Ehrenfeld and Schneider (1990) found a relationship between stormwater discharge and changes in plant community composition in the New Jersey Pinelands; there was a reduction in indigenous wetland species and colonization of exotic species due to changes in hydrology, water quality, or both. Wetland plant species may have a limited ability to migrate in the face of persistently raised water levels; many species can spread only through clonal processes in wetland water level may alter the quantity and quality of amphibian habitat, triggering changes in breeding patterns and species composition (Minton, 1968 in Azous, 1991). Egg development may be impacted by a decline in WLF by potential exposure and desiccation when stranded on emergent vegetation (Lloyd-Evans, 1989 in Azous, 1991). WLF may also cause changes in water temperatures, which may impact egg development (Richter et al., 1991).

Freshwater hydrologic disturbances were also correlated to responses of fish and macrobenthic assemblages (Nordby and Zedler, 1991). In the study, two coastal marshes with different hydrology, one of which was impounded from tidal action, were compared. Results show that the fauna was most depleted where the hydrologic disturbances were the greatest, with the trends over the course of the study being reduced species richness and abundance.

Among potential impacts brought up by workshop participants was the mortality of eggs or young of waterfowl due to flooding during the nesting period. Also, continuity of habitat around wetlands receiving stormwater may be important in allowing wildlife free movement and refuge during storm events.

Wetland mammal populations may potentially be affected by change in hydroperiod because of the loss of vegetative habitat and the increased potential for disease organisms and parasites due to shallower, warmer base flow conditions (Lloyd-Evans, 1989 in Azous, 1991).

Changes in water quality (chemistry and sediment loading) have the potential to affect the vegetative community structure and to reduce the availability of plant species preferred by fish, mammals, birds, and amphibians for food and shelter (Lloyd-Evans, 1989 in Azous, 1991; Mitsch and Gosselink, 1986; Weller, 1987 in Azous, 1991). For example, Azous (1991) found that plant community richness, evenness, and dominance were negatively correlated with the presence of total organic carbon in the water column. Further studies are needed to determine the levels of heavy metal concentrations in the water column that will affect the plant species diversity in the wetland.

Despite the fact that little work has been documented on the effects of water quality changes on aquatic organisms, such changes have the potential to impact life cycles. The ability of aquatic organisms, especially amphibians, to readily absorb chemicals suggests that they are responsive monitors of wetland conditions (Richter and Wisseman, 1990). Richter et al. (1991) state that significant negative correlations were found between amphibian species richness and water column conductivity. Negative changes in water quality and potential accumulation in soils and macrobenthic organisms suggest that bioaccumulation may occur in the bird and mammal communities. Further studies are required to determine whether bioaccumulation is occurring and to what degree.

The habitat requirements, life histories, and species assemblages of wetland communities are relatively unknown at this time, requiring further investigation before impacts from stormwater discharges into wetlands can be determined.

## REGIONAL DIFFERENCES

The degree and character of impacts to natural wetlands due to urban stormwater runoff described above will vary from region to region and even from site to site. These impacts will vary due to regional differences in storm events, wetland types, watershed characteristics, and pollutant loads. For example, geographical areas with Type II and III rain distributions (see Chapter 4) are those in which relatively intense detain stormwater during rainfall events for later gradual release to the San Francisco Bay during low tides (ABAG, 1991). When a wetland is partly or wholly impounded for stormwater management, its water quality improvement, flood attenuation, sediment retention, or groundwater recharge capabilities are being exploited, possibly at the expense of other wetland functions such as habitat for fish and wildlife.

An impoundment is defined as a body of water confined by a dam, dike, floodgate, or other barrier (USEPA, 1989). Often the impoundment of a wetland (e.g., for stormwater treatment) results in changes in the wetland. These changes may result in such extreme modifications that the functional characteristics of a wetland, such as hydrology, soils, or water quality, are affected. Such modifications may include the drawdown to be controlled (Thompkins, 1986). Studies have shown, however, that water circulation patterns within impounded wetlands appear to be responsible for many of the differences between these systems and natural wetlands. The degree to which wetlands export carbon and nutrients is dependent in large part on the hydrologic characteristics of a system. Changes in these characteristics as the result of impoundment or hydrologic manipulation can change this export. Reduced circulation in impoundments can result in higher water temperatures and increased evaporation rates during the summer, as well as fluctuations in dissolved oxygen and salinity and other changes associated with water quality. The manipulation of wetland hydrology can also directly influence the availability of aquatic habitat and indirectly affect invertebrates through the physiological responses of hydrophytes (Reid, 1982). Therefore, an understanding of the amount and timing of water exchange is important to the success of these systems.

## WATER QUALITY CHANGES

Although few studies directly relating stormwater inflow to water quality changes in impounded wetlands were identified in the literature, some comparisons between impounded and open wetlands can be considered. Suspended particles are typically the pollutant of concern. Sedimentation of suspended particles is one of the principal was determined to be the primary removal mechanism in the system. Table 13 shows the removal rates of phosphorus and other measured parameters by the impounded wetland over the 6-year period. The impoundment of wetlands also removes acreage from open wetland systems and may diminish the overall export of detritus from the systems (Devoe and Baughman, 1986). Other differences in nutrient exchange were associated with basic biological and geochemical differences that characterize the impounded versus intertidal environments (McKeller, 1986). Wetland impoundments in the South Carolina study were dominated by submerged benthic communities rather than open emergent intertidal marsh systems. These basic differences exert considerable control over the ways in which nutrients are processed and exchanged in wetland systems.

The impounded and open tidal marshes in the South Carolina study (McKeller, 1986) were both shown to export particulate and dissolved carbon. The nature of the carbon export was not determined. Differences in the quality of organic matter being exported are important in determining the overall impacts of impounded versus open wetlands on adjacent receiving waters (McKeller, 1986).

Salinity in impounded systems has been shown to fluctuate as the result of several factors, including reduced circulation, increased evaporation, and a lack of exchange.

summer, concentrations move between the upper and lower shaded areas rapidly as organic matter is processed and wind mixing or photosynthesis occurs. Dashed lines depict areas of limited data.

Water temperatures in shallow impoundments have also been shown to vary compared to those of adjacent natural marshes and free-flowing streams in north central Minnesota. While minimum temperatures in impoundments were shown to be the same as those in natural systems, the maximum temperatures were as much as 5 degrees Celsius higher in the impounded wetlands (Verry, 1982). The higher maximum temperatures were shown to be associated with surface-water-fed impoundments that were stagnant, with diminished depths and little or no water flow. Decreased water depths and flow were associated with dry weather conditions or intentional management drawdowns (Verry, 1982). The effect of higher water temperature in shallow impoundments on downstream water temperatures was also examined by Verry (1982). Temperatures were shown to drop from 24.5 ºC to 20.5ºC within 20 meters of a shallow impoundment outlet (Verry, 1982). Temperatures remained the same farther downstream. The rapid decrease in water temperature leaving the impoundment was attributed by Verry to streamside shading and groundwater influx. The difference in temperature downstream from the outlet was close to the temperature difference between the impoundment and the natural stream.

## SOIL CHANGES

The increased capability to control flow characteristics and exchange in impounded wetlands can result in a more efficient removal of suspended sediment from the water column. Increased sedimentation and management of water levels in impounded wetlands can affect the soils within the system. Lack of daily flushing by tides in impounded wetlands in South Carolina resulted in a greater accumulation of organic material in the soils as compared to adjacent natural marshes (May and Zielinski, buildup of materials in the soil. Improper management techniques in impoundments used for stormwater runoff could result in the reintroduction of these toxicants to the water column during turbulent conditions associated with storms or high-flow events.

High percentages of silt-sized particles in combination with low sedimentary flushing of smaller particle sizes can result in decreased oxygen levels in impounded wetlands. Oxygen depletion can result and in brackish or saltwater environments may be accompanied by the accumulation of sulfides (Wenner, 1986). The accumulation of organic material can also result from oxygen depletion. Management of water levels in impounded wetlands can also cause leaching and oxidation of marsh soils. If soils are not kept moist, sulfides can become oxidized to form sulfuric acid and cat clays (Wenner, 1986). The development of acid sulfate soils or cat clays can result in a soil pH of 3.5 or less. Soil samples taken in a brackish marsh impoundment that had been dewatered on South Island in South Carolina had pH values ranging from 3.2 to 8.3, depending on whether the soils were kept wet or allowed to dry (Wilkinson, 1970).

## BIOLOGIC/HABITAT IMPACTS

Changes in the types and diversity of vegetation in wetlands have been shown to occur as the result of the impoundment of these systems. Additional changes in vegetation could be expected as the result of stormwater discharges to impounded wetland systems. As mentioned above, plant communities and individual species appear to be affected by water depth, frequency and duration of flooding, and water quality. Studies in impounded marshes along Florida’s east coast showed that excessive or prolonged flooding in wetland impoundments resulted in the stressing or killing of existing high marsh vegetation in the systems (Carlson and Carroll, 1985).

Another basic change associated with the impoundment of intertidal marshes is the conversion from a wetland dominated by emergent vegetation to a system dominated largely by submerged macrophytes, benthic algae, and phytoplankton (Kelly et al., 1986). Although total community production in managed wetland impoundments in South Carolina was shown to be similar to total production in adjacent open marshes, the contributions to productivity of the various plant communities (marsh grasses, benthic macrophytes and macroalgae, and phytoplankton) were shown to differ considerably between the impounded and open marshes (Marshal and McKeller, 1986).

Wilkinson (1970) conducted studies on a newly flooded brackish impoundment on South Island in South Carolina to determine vegetative succession in the system. Water depths in the wetland impoundment ranged from 12 to 24 inches. During a 3-year study period, the relative abundance of some species changed drastically with the distribution of plants into zones associated with water depth. *Ruppia maritima*, a submerged aquatic grass, became the most successful plant after flooding. *Scirpus* *robustus* was the most successful emergent plant. *Distichlis spicata*, a salt grass associated with higher portions of salt marshes, decreased in abundance after flooding and eventually disappeared from the impoundment; *Spartina cynosuroides*, a shallow water emergent, was reduced in area of coverage to the very shallow margins of the impoundment (Wilkinson, 1970).

In freshwater impoundments in South Carolina where water levels are maintained, floating and submergent species have been shown to become the dominant vegetation in succession. The dominant species vary according to water depth, but Utricularia, a submerged aquatic plant, *Lemna*, a floating aquatic plant, *Nymphaea*, a floating leaved aquatic plant, and *Ceratophyllum* impoundment. Salinities ranged from 2 to 125 ppt, water temperatures were from 14 to 34 ºF" , and oxygen levels varied from 1.2 to 14.4 ppm (Gilmore et al., 1981). The number of species collected in the impoundment after dewatering was reduced to four. Figure 9 shows the monthly distribution of fish in relation to salinity, rainfall, and water levels in the impoundment during the study period (Gilmore et al., 1981). Fluctuations in rainfall, salinity, and water depth during the month of September were the result of Hurricane David.

Earlier studies conducted on the marsh by Harrington and Harrington in 1966 prior to and 30 months after initial impoundment showed a reduction in the number of fish species from 16 to 5. Studies also indicated a change in feeding habits to a reliance on plant materials by three of the remaining species in the impoundment (Harrington and Harrington, 1982).

Shallow impoundments in north central Minnesota with reduced or stagnant water flows were determined not to be well suited for fish populations during the summer and over winter because of rapid and wide fluctuations in dissolved oxygen levels (Verry, 1982). Maximum water temperatures in the impoundments were also shown to be above the upper level for normal trout growth. Maximum temperatures in wetland

The use of impounded wetlands by water birds has been shown to be high in several systems. Studies conducted on South Carolina impoundments indicated that high water bird use was directly related to season, management practices, impoundment size, and availability of resources (Epstein and Joyner, 1986).

Newly impounded brackish wetlands on South Island, South Carolina, were studied by Wilkinson (1970) over a 3-year period to determine plant succession and waterfowl use. Five impoundments with different hydrologic controls—fully flooded, slowly rising, tidal, saturated soil, and dry—were observed. Use of the impoundments by waterfowl was rated based on the estimated number of observed waterfowl. Observed numbers of 1 to 10 were rated as poor, 10 to 30 as fair, 30 to 60 as good, and above 60 as excellent (Wilkinson, 1970). Waterfowl observations were made twice a week during the fall and winter. The fully flooded impoundment was the most used by waterfowl. Use of the wetland impoundment with rising water levels was rated good, and use of the tidal impoundment was good to poor. Use of the impoundment with saturated soil was rated as fair to poor, and use of the dry impoundment was rated as poor (Wilkinson, 1970).

In Minnesota, Wisconsin, and Michigan, surveys of impoundments indicated that after initial flooding the diversity and density of birds increased due to increased edge, productivity, nest cavities, and perch sites (Rakstad and Probst, 1982). The increase in amount of edge and degree of interspersion of habitat types also resulted in use by greater numbers and kinds of wildlife including muskrats, racoons, red fox, river otter, mink, and water shrew (Rakstad and Probst, 1982). After several years, however, the density and diversity of wildlife has been shown to have decreased in many impoundments. This decrease has been shown to be due in part to vegetative succession in the impoundments.

Some management techniques applied to wetland impoundments have been shown to be successful in maintaining or enhancing use by wildlife in several cases. The water quality salinity and hydrology requirements of different fish and wildlife species vary, and therefore management techniques applied to wetland impoundments to increase or enhance habitat for one species may have adverse impacts on others (Hynson et al., 1985).

## **REGIONAL DIFFERENCES**

Regional differences that affect impounded wetland systems are similar to those that affect natural wetlands. The methods, timing, and period of drawdowns depend largely on the geology, hydrology, soils, and climate of an impoundment site. For example, soils in arid regions with low rainfall tend to accumulate salts in their upper profiles. As a result, drawdowns or evaporation in arid-region impoundments can result in the development of hypersaline conditions. Such conditions would be less likely to occur in humid regions. In addition, northern regions are more likely to be affected by the ice-over of impoundments in winter than are southern regions. These regional and site-specific characteristics, in addition to others, all exert controls on the inflow, outflow, and quality of water in an impoundment.

## SUMMARY

Shallow-water impoundments have been shown to be both potentially beneficial and potentially detrimental to the functions of the impounded wetland systems. The increased ability to manipulate the hydrology in impoundments (i.e., water levels and flow) allows management techniques to be designed to enhance or control specific aspects of the systems. For example, water levels can be controlled to enhance the growth of certain vegetative species and in turn attract certain waterfowl or wildlife. Flow within the impoundments can be controlled to promote increased sedimentation of pollutants from inflowing stormwater. However, altering the hydrology in a natural system by impoundment or through the management of impounded systems can change the functional processes of the system. As mentioned, techniques applied to impoundments to enhance or control one aspect within the system can result in adverse impacts to others. Changes in the characteristics of the hydrology, water quality, soil, vegetation, and fauna in the impoundment can result.

As the result of urbanization, in many areas low- to moderate-intensity storms can produce large volumes of runoff. Because of the variable nature of stormwater runoff flow, the ability of impounded wetlands to remove nutrients, suspended solids, and heavy metals may vary by season, from storm to storm, or within the same storm (ABAG, 1991). Impoundments may act as a sink for the constituents of stormwater under certain conditions or as a source under others. Variations in the characteristics of stormwater inflow will also have varying impacts on the components of impoundments. Changes in the characteristics of the soil, water quality, and hydrology in impoundments will occur and, in turn, will affect the biota in the impounded wetland. The potential bioaccumulation of pollutants for fish and wildlife as the result of stormwater inflows remains unclear (Meiorin, 1986). The effects of impounding wetlands and manipulating impoundment conditions, along with the

- Better understanding of the long-term impacts of water level fluctuations on wetlands and wetland functions, particularly habitat functions, is needed.

- Threshold levels for the volume and quality of stormwater entering and discussed in the previous section) are listed below:

- Better understanding of the amount and timing of water exchange in impoundments in order to improve water circulation patterns in the system is needed.

- Increased understanding of techniques to improve the exchange and circulation between impounded wetlands and open systems is needed.

- Better understanding of the technical aspects of the long-term management of impounded wetlands for optimal stormwater control needs to be developed.

- Better understanding of the impacts of the constituents of stormwater on the water quality, soils, vegetation, and fauna of impoundments is including stormwater runoff. This guidance, and other Federal and State legislation, has led to the development of stormwater management programs and suggestions for managing urban stormwater runoff, on both a watershed level and a site-specific level. This chapter discusses urban stormwater management programs and implementation tools for controlling adverse impacts from stormwater runoff, including the relationship of such programs and tools to natural wetlands.

## FEDERAL AND STATE STORMWATER MANAGEMENT PROGRAMS

While the Federal government provides guidance for the control of nonpoint source pollution, the only Federal regulations for stormwater runoff are promulgated through the NPDES permitting process (section 402 of the Clean Water Act). Section 402 authorizes EPA to issue permits to discharge pollutants into waters of the United States if States do not have an approved NPDES permit program in place. The majority of the States are NPDES delegated; therefore, most stormwater controls are implemented at the State and local government levels. In addition, as part of the Coastal Zone Act Reauthorization Amendments of 1990, Congress created a new section 6217, which requires States with approved coastal zone management programs to develop and implement coastal nonpoint pollution control programs. The National Oceanic and Atmospheric Administration (NOAA) and EPA recently developed guidance to implement these requirements. They are also responsible for reviewing and approving State programs and providing technical assistance to the States. Under section 303, EPA has issued guidance for States to develop water quality standards. This guidance will have an impact on regulated stormwater discharges to wetlands. The State standards must address wetlands as waters of the State, set appropriate narrative and numeric criteria, and establish an antidegradation policy. States can establish narrative or numeric hydrologic and biologic criteria that address stormwater impacts.

Construction of certain stormwater management systems, including the impoundment of natural wetlands, may involve the discharge of dredged or fill material into waters of the United States, which include wetlands. These discharges are regulated under section 404 of the Clean Water Act, which is administered by the Army Corps of Engineers and EPA. Questions regarding the applicability of section 404 to stormwater activities need to be addressed prior to initiation of construction.

The extent and requirements of State and local stormwater management programs vary. Many, but not all, States have stormwater management programs, and many local governments are required by the State to develop stormwater management programs consistent with or stronger than the State guidelines. In some States, local controls for stormwater runoff are the only controls in place, and they have been developed voluntarily.

For those states with stormwater management programs, some allow the use of natural wetlands as part of a permitted stormwater treatment system. Many states do not have enabling legislation to allow this, but they realize that runoff impacts wetlands by default and have therefore developed general guidelines for wetlands. Some state guidelines aim to prevent direct discharge of stormwater to natural wetlands without appropriate pretreatment. The broad range of requirements and general criteria that some states have developed for using natural wetlands in stormwater management is presented in Table 14.

Few states have formal administrative rules or regulations that address hydrological and chemical changes that may occur to wetlands as a result of stormwater discharges.

In most instances, stormwater management systems involve more than one practice. To effectively manage urban runoff, a series of measures may be used. Many States that do allow the use of wetlands require that other control measures be used as well, usually prior to discharge to the wetland.

As discussed in Chapter 5, alteration of the wetland environment may occur if wetlands are used for the treatment of urban stormwater runoff. However, adverse impacts can be minimized, both from a site-specific and watershed-wide perspective.

## CONCLUSIONS

The use of wetlands for treating urban stormwater runoff is not an isolated activity; it is usually part of a larger stormwater management system addressing both water quality and quantity. Some States have stormwater management programs; however, the use of natural wetlands as part of stormwater management systems may not be specifically regulated by the State. If the use of natural wetlands as part of stormwater management systems involves the discharge of dredged or fill material to waters of the United States, it would be regulated under section 404 of the Clean Water Act. Water quality, water quantity, and physical modification can impact a wetland system. These parameters do not necessarily follow political boundaries; therefore, overall watershed planning can help to anticipate and prevent adverse impacts from urban stormwater runoff.

## UNRESOLVED ISSUES

Unresolved issues related to stormwater management practices include the following:

- Many States do not have statewide stormwater management programs; consequently, stormwater runoff to natural wetlands occurs without consideration of the impacts to the system. This occurrence may be contradictory to wetland preservation efforts in some States.

- Most Federal and much State guidance incorporating stormwater controls addresses water quality and water quantity separately.

- Watershed management practices need to be implemented to minimize the impacts of stormwater discharges on natural wetlands.

- The circumstances under which stormwater discharges to natural wetlands should be allowed need to be identified.

- Many local jurisdictions require regional stormwater ponds for new developments. Wetlands are often the only remaining undeveloped land and are the lowest points in the landscape to receive stormwater runoff. Are there alternatives that minimize impacts and meet stormwater management objectives?

The need for integration of various local, State, and Federal authorities with jurisdiction over wetlands and stormwater discharges was raised at the January 1992 workshop.

# 7. SUMMARY

Although wetlands have long been recognized for their flood control and water quality improvement functions, there is increasing concern that unrestricted use of natural wetlands as receptacles for point and nonpoint sources of pollution, such as urban stormwater, will have adverse effects on wetlands and wetland biota. These impacts will vary from site to site and region to region. However, if natural wetlands are the ultimate receiver of stormwater runoff, either inadvertently or by design, the potential impacts of such discharges need to be better understood and management practices need to be designed to minimize these impacts.

This issue paper has identified several unresolved issues related to the use of natural wetlands for urban stormwater control. These and other issues were discussed at the Wetlands and Stormwater Workshop held in January 1992 in Clearwater, Florida. The purpose of these discussions was to share ideas and opinions and make recommendations on how to best manage the discharge of urban stormwater to natural wetlands. Information from the workshop has been incorporated into this issue paper. The unresolved issues identified in this paper are summarized below.

## WETLAND FUNCTIONS

- In-depth knowledge of the totality of wetland functional support, taking into consideration such factors as nutrient flows, hydrology, trophic dynamics, community structure, and population distribution and abundance, is not available for most wetland types.

- A greater understanding of habitat processes and functions and how identified.

- Better understanding of the long-term impacts of water and sediment quality changes on wetland biota is needed.

- The potential benefits to natural wetlands (i.e., enhancement) due to stormwater discharges need to be better understood and considered in stormwater management.

- Increased recognition and understanding of regional differences and concerns associated with natural wetlands, including hydrologic differences and wetland types, are needed:

- Increased understanding of the public health risks associated with the storage of urban stormwater in natural wetlands is needed.

- There is a lack of understanding and methods to measure and assess how changes in wetland processes due to urban stormwater discharges affect the support of biological communities.

## MANAGEMENT OF STORMWATER DISCHARGES

- Many States do not have statewide stormwater management programs; consequently, the discharge of urban runoff to natural wetlands occurs without consideration of the impacts to the system. This occurrence may be contradictory to wetland preservation efforts in some States.

- Most Federal and much State guidance incorporating stormwater controls addresses water quality, not water quantity. The potential changes in hydrology and their impact must be addressed as well.

- Watershed management practices need to be implemented to minimize the impacts of stormwater discharges on natural wetlands.

- The circumstances under which stormwater discharges to natural wetlands

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# GLOSSARY[1]

**Absorption:** A process in which one material takes up and retains another; to take a substance, as water or nutrients, into the body through the skin or mucous membranes or, in plants, through root hairs.

**Adsorption:** The ability to attract and concentrate upon surfaces molecules of gases, liquids, and dissolved solids; the adhesion of molecules to the surfaces or liquids with which they are in contact. Many pollutants adsorb to sediment particles and are transported by these particles.

**Aggressive plant species:** Opportunistic species of inferior biological value that tend to outcompete more desirable forms and become dominant. Term applied to native species; *invasive* is term applied to non-native species with similar characteristics.

**Alkalinity:** A measure primarily of the carbonate or carbon dioxide-related compounds in water. The lower the alkalinity, the less capacity the water has to absorb acids without becoming more acidic. Therefore, alkalinity is a measurement of the buffering capacity of water.

**Ammonia ($NH_3$):** A nitrogen-containing compound that may indicate recently decomposed plant or animal material.

**Antecedent soil condition:** The soil moisture condition at the start of a storm event. The soil moisture condition prior to a storm event influences the amount of runoff.

**Beneficial uses:** Uses of a waterbody that provide benefits to human users, such as swimming, fishing, boating, fish spawning and rearing, water supply, and wildlife habitat.

**Best Management Practice (BMP):** A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a waterbody. BMPs generally fall into two categories: source control BMPs and stormwater treatment BMPs. The term originated from the rules and regulations developed pursuant to section 208 of the Federal Clean Water Act (40 CFR 130).

**Bioaccumulation:**

**Biochemical oxygen demand (BOD):** An index of the quantity of oxygen-demanding substances (organic matter subject to bacterial decay) in a sample as measured by a specific test. Although not a specific compound, BOD is defined as a conventional pollutant under the Federal Clean Water Act. During bacterial decay and digestion processes, oxygen is used, reducing dissolved oxygen levels in the water column. Sources of BOD include sewage treatment and septic tank effluents, oil and grease, pesticides, organics of natural origin, and any other decomposable material. Sewage effluents from secondary treatment have a BOD level of 30 mg/L. Urban runoff can have a BOD level equal to or greater than that of sewage effluents. (See **chemical oxygen demand (COD)**.)

**Bioengineering:** Restoration or reinforcement of slopes and stream banks with living plant material.

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**[1] Adapted from Stockdale, 1991.**

**Biofiltration:** The processes by which stormwater or wastewater receives treatment through interaction with vegetation and the soil surface. These processes include (1) sheet flow over a broad, vegetated surface area (filter strip); (2) flow at some depth through a vegetated channel, or swale; and (3) use of small, created wetlands, developed specifically for local stormwater management purposes.

**Biomagnification:** The process by which concentrations of contaminants increase

**Contaminant:** A substance that is not naturally present in the environment or is present in amounts that can, in sufficient concentrations, adversely affect the

**Enhancement:** Actions performed to improve the condition of an existing degraded wetland so that the functions it provides are of a higher quality. (See **created wetland, restoration**.)

**Erosion:** The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices.

**Estuarine:**

**Hydric soils**: A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part.

**Hydrology:** The properties, distribution, and circulation of water. Wetland hydrology is the total of all wetness characteristics in areas that are inundated for a sufficient duration to support hydrophytic vegetation.

**Hydroperiod:**

shallow water and abundant emergent, floating, and submergent wetland flora. Typically found in shallow basins, on lake margins, along flow gradient rivers, and in low-energy tidal areas. Waters may be fresh, brackish, or saline.

**Metals:** Elements found in rocks and minerals that are naturally released to the environment by erosion, as well as generated by human activities. Certain metals, such as mercury, nickel, zinc, and cadmium, are of environmental concern because nitrite is usually present only in small quantities in water.

**Nitrification:** The process of oxidizing nitrogen compounds to nitrites and nitrates, usually by bacterial action.

**Nitrogen:** A nutrient plants can take up in various forms. The nitrogen cycle in wetlands can include several nitrogen sinks with nitrogen being lost as a gas, adsorbed to soil particles, and incorporated into organic material.

**Nonpoint source (NPS) pollution:** Typically defined as pollution that is not discharged through pipes but rather originates from a multitude of sources over a large area. Nonpoint sources can be divided into source activities related to either land

**Petroleum hydrocarbons:** A collective term for motor vehicle fuels, lubricating oils and greases, tars, and asphalts. The sources of petroleum hydrocarbons in urban runoff include partially burned fuels in motor vehicle exhausts, general leakage from motor vehicle engines and drive lines, improper disposal of waste crankcase oil in gutters and storm drains, and accidental spillage.

**pH**: A measure of the alkalinity or acidity of a substance, which is conducted by measuring the concentration of hydrogen ions in the substance. pH is measured on a scale from 1 to 14, with 1 indicating the most acidic, 7 indicating neutral, and 14 the most basic or alkaline. The pH of water influences many of the types of chemical reactions that will occur in it.

**Phenol:** A caustic poison composed of acidic compounds that are generally derived from aromatic hydrocarbons.

**Phosphorus:** A nonmetallic element that occurs widely and is essential to the growth of aquatic organisms as well as all forms of life. In aquatic environments, phosphorus is often the nutrient that limits the growth that a body of water can support. Additions of phosphorus to wetlands can cause increased vegetative growth and modifications to community composition. Phosphorus can be reduced in wetland systems by plant uptake and by adsorption to soil and organic material.

**Point source:** A source of pollutants from a single point of conveyance such as a pipe. For example, the discharge pipe from a sewage treatment plant or a factory is a point source. See **nonpoint source** for comparison.

**Pollutant:** A contaminant in a concentration or amount that adversely alters the physical, chemical, or biological properties of the environment. The term includes pathogens, toxic metals, carcinogens, oxygen-demanding materials, and all other harmful substances. With reference to nonpoint sources, the term is sometimes used to apply to contaminants released in low concentrations from many activities that collectively degrade water quality. As defined in the Federal Clean Water Act, pollutant means dredged spoil; solid waste; incinerator residue; sewage; garbage; sewage sludge; munitions; chemical wastes; biological materials; radioactive materials; heat; wrecked or discarded equipment; rock; sand; cellar dirt; and industrial, municipal, and agricultural waste discharged into water.

**Polynuclear (polycyclic) aromatic hydrocarbons (PAHs or PNAs):** A class of complex organic compounds, having more than one benzene ring, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAHs are commonly formed by the combustion of gasoline and by forest fires. They often reach the environment through atmospheric fallout and highway runoff.

**Pretreatment:** The treatment of wastewater to remove contaminants prior to discharge into a municipal sewage system, or the treatment of stormwater (such as in a grassy swale or sediment trap) prior to discharge downstream

**Primary Treatment:** A basic wastewater treatment method that uses settling, skimming, and (usually) chlorination to remove solids, floating materials, and pathogens from wastewater. Primary treatment typically removes about 35 percent of BOD and less than half of the metals and toxic organic substances.

**Priority pollutants:** Substances listed by EPA under the Federal Clean Water Act as toxic and having priority for regulatory controls. The list includes metals (13), inorganic compounds (2), and a broad range of both natural and artificial organic compounds (111).

**Receiving bodies of water:** Creeks, streams, rivers, lakes, and other bodies of water into which surface waters (and treated or untreated wastes) are directed, either naturally or in man-made ditches or open systems.

**Recharge:** The flow to groundwater from the infiltration of surface and stormwater runoff.

**Redox potential:** A measure of the intensity of oxidation or reduction of a chemical or biological system. The redox potential of hydric soils indicates the state of oxidation (and hence the availability) of several nutrients. For example, phosphorus is more soluble under anaerobic conditions.

**Refractory organics:** A term recently developed to identify a broad lumping of man-made organic chemicals that are refractory; that is, they resist chemical or bacterial decomposition. Included in this class are many pesticides, herbicides, household and industrial cleaners and solvents, photofinishing chemicals, and dry-cleaning fluids.

**Regional detention facility:** A stormwater quantity control structure designed to correct the existing excess surface water runoff problems of a basin.

**Restoration:** Actions performed to reestablish wetland functional characteristics and processes that have been lost by alterations, activities, or catastrophic events in an area that no longer meets the definition of a wetland. (See **enhancement**, **created wetland.)**

**Retention:** The collection and holding of surface and stormwater runoff with no surface outflow.

**Retention/Detention (R/D) facility:** A type of drainage facility designed (1) to hold runoff for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground or (2) to hold runoff for a short period of time and then release it to the surface and stormwater system.  Most facilities do both to some degree.

**Stormwater:** Rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces but instead flows onto adjacent land or watercourses or is routed into drain/sewer systems.

**Structural control:** Methods for managing stormwater that involve altering the flow, velocity, duration, and other characteristics of runoff by physical means, e.g., construction of a detention dam and weir.

**Surface water:** Water present above the substrate or soil surface.

**Suspended solids:** Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, mud, and clay particles, as well as solids in wastewater. High levels of suspended solids can clog the breathing gills of some fish and suffocate them. When suspended solids settle to stream and lake bottoms, they can clog salmon spawning gravels, suffocating salmon eggs and/or preventing future spawning. Clay and silt sediment particles generally carry other pollutants adsorbed to their surface, including petroleum hydrocarbons, refractory organics, pesticides, and heavy metals.

**Swale:** A shallow drainage conveyance with relatively gentle side slopes, and generally with flow depths less than one foot. Water quality swales are open vegetated drainage channels intended to optimize water quality treatment of surface and stormwater runoff according to specific design criteria.

**Swamp:** A forested wetland with a shallow water table; palustrine forested wetlands, dominated by woody vegetation greater than 6 meters (20 feet) in height.

**Total suspended solids (TSS):** A measure of the amount of suspended solids found in the water column.

**Toxic:** Poisonous, carcinogenic, or otherwise directly harmful to life.

**Toxic substances and toxicants:** Chemical substances, such as pesticides, plastics, heavy metals, detergents, organics, chlorine, oil, and industrial wastes, that are poisonous, carcinogenic, or otherwise directly harmful to life.

**Treatment:** Chemical, biological, or mechanical procedures applied to an industrial the turbidity of the water decreases the depth to which light can penetrate. High levels of turbidity over extended periods are harmful to aquatic life.

**Volatile:** Readily vaporizable at a relatively low temperature.

**Wastewater:** Effluent from a sewage treatment plant.

**Water quality:** The biological, chemical, and physical conditions of a waterbody; measure of a waterbody's ability to support life.

**Watershed:** The geographic region within which water drains into a particular river, stream, or body of water. A watershed includes hills, lowlands, and the body of water into which the land drains. Watershed boundaries are defined by the ridges separating watersheds. Every activity on the surface of the land within a watershed can send pollutants into the water.

**Water table:** The upper surface of groundwater in the zone of saturation.

**Wetland hydrology:** In general terms, permanent or periodic inundation or prolonged soil saturation sufficient to create anaerobic conditions in the soil.

**Wetlands:** Lands transitional between terrestrial and aquatic systems that have a water table usually at or near the surface or a shallow covering of water, hydric soils, and a prevalence of hydrophytic vegetation. Note that there are several versions of this definition. Refer to agency definitions (U.S. EPA/Army Corps of Engineers, U.S. Fish and Wildlife Service) for a more precise definition.