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WATER QUALITY, ECOLOGICAL, AND FLOOD CONTROL BENEFITS OF URBAN STORMWATER MANAGEMENT PRACTICES

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CHAPTER 1

INTRODUCTION

Urban streams and lakes are typically deteriorated, dating back to Roman times and even before. The main reason why Romans built their aqueducts and brought water to their city from larger distances was a simple fact that the River Tiber and other rivulets transecting the city of almost one million were grossly polluted by urban runoff that also carried domestic waste (Hansen, 1983). Throughout the recent history, as a result of urbanization, urban streams have been channelized, constricted, and ultimately covered to gain space for urban development and to accommodate increased flood flows. Examples of Los Angeles River in California or the portions of the Menomonee River, Lincoln Creek and other streams in Milwaukee (Figure 1.1) represent the ultimate transformation of an urban stream into a concrete high flood velocity channel with a very little biological habitat. Concurrently, as a result of these modifications and worsening of water quality, indigenous pollution sensitive aquatic species have disappeared, resulting in propagation of few unwanted species tolerant to pollution and low quality habitat.

Urbanization typically has an irreversible impact on natural drainage patterns and flows in the receiving water bodies impacted by development. If the development progresses in a planned, ecologically conscious way, the adverse impacts on population and properties can be minimal or minimized. Uncontrolled developments or past development in the flood plain that did not consider the impacts on hydrology, flood plain encroachment, morphology and ecology of the receiving water body system have had detrimental effect on the receiving water body, flood plain development and downstream uses of the water body.

Management of urban streams today must today consider several objectives and uses such as

- I. Flood control
- II. Preservation and restoration of ecological integrity of the receiving water body
- III. Providing contact and noncontact recreation to urban population
- IV. Other lesser uses such as water supply, navigation, or hydropower production

Since these objectives and uses are often conflicting, the conflicts must be reconciled and uses must be optimal.

Hydrologic Changes of Streams by Urbanization

Urbanization has numerous effects on the urban receiving water bodies. The most important impact is the alteration of the hydrological cycle and rainfall-runoff transformation process. By urbanization, watersheds become more impervious, resulting in a dramatic shift of flow components and origin in the streams. In a hydrological situation of watershed located in Midwestern and Eastern United States, streams that originally (pre-development stage) received significant portion of flow from groundwater-base flow contribution were hydrologically and morphologically changed into drainage channels that receive most of their flow from surface runoff.

The increased magnitude and frequency of high flows has several major adverse effects on the part of the community and development located near the water course, on the floodplain and on the ecology of the urban stream. The hydrologic effects can be summarized as :



Figure 1.1. Channelized portion of the lower Menomonee River in Milwaukee (Piggsville)

1. The floodplain enlarges. Figure 1.2 shows that as the magnitude of the 100 year flood increases, areas that were outside the 100 year flood plain would become a part of it.
2. The frequency of flooding inside the floodplain increases.
3. Since surface flow moves faster the time of concentration is decreased. As a consequence, peak flows during storm events are increased.
4. Magnitude and frequency of all runoff events of all sizes increases. This is especially important for rainfalls of smaller and medium magnitudes. Before urbanization these smaller rainfalls mostly infiltrated into soil and the flows in the stream were smaller and could be easily contained in the natural channels of the stream. After urbanization the same medium rainfall could result in a flood.
5. As a result of increased medium floods channels become unstable and more erosive (degrading).
6. Imperviousness impedes recharge of shallow groundwater aquifers. This diminishes the base flow contributions. After urbanization some streams may become ephemeral or effluent dominated.

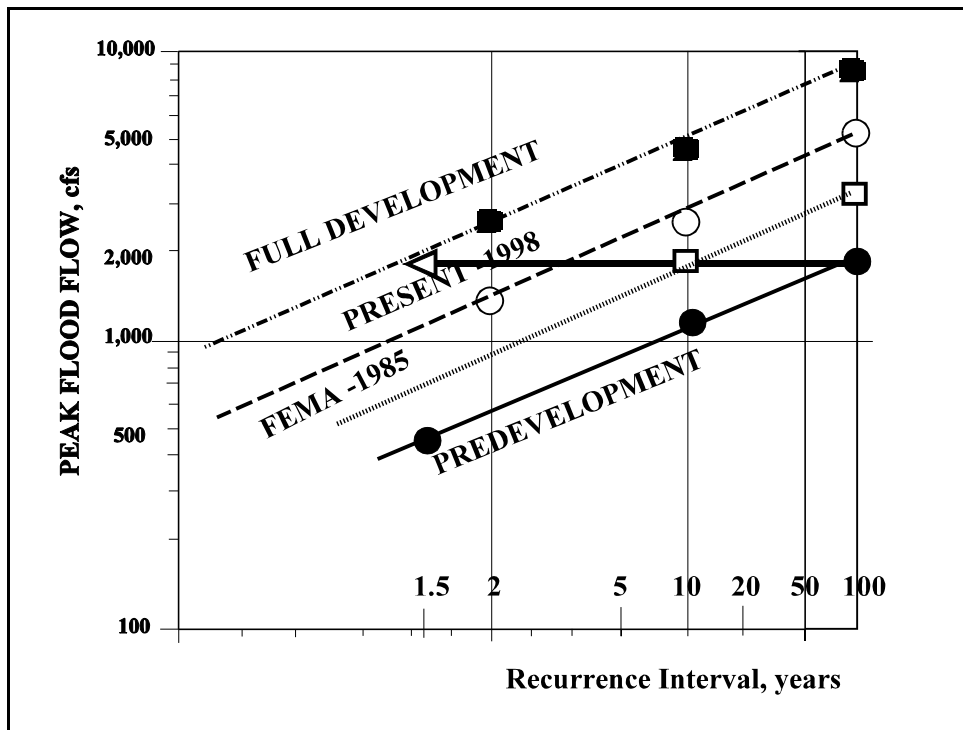


Figure 1.2. Hydrologic effects of urbanization on a small stream with soils of medium permeability (SCS hydrologic category B and C)

7. More flow moves on the surface with a faster velocity. This increases the volume of surface runoff contribution.

Figure 1.3 shows an example of urban flooding in Milwaukee partially caused by urbanization and partially by the insufficient capacity of the inverted siphon that could not handle the increased flood flows.

Citizens of communities subjected to frequent flooding typically assume that installation of storm sewers, flood proofing lift stations on sanitary sewers and similar infract will alleviate the flooding problems. In should be emphasized that these urban drainage infrastructure component are typically designed to handle storms that have a recurrence interval from five to ten years. These infrastructure components are part of so called *convenience* urban drainage systems that have an objective to keep streets and driveways free of excessive standing water. These components do almost nothing to resolve problems caused by large storms. The *major system* that conveys floods up to 100 magnitude should have an objective to minimize the damages caused by the flood bu not completely eliminate the inconvenience cause by water in the floodplain. Today flood management relies on floodplain management, including relocation of families outside the floodplain and on stream storage. Designing minor drainage to handle large storm in excess of a ten year recurrence interval storm would be prohibitively costly; often the cost would exceed the value of properties located in the floodplain.



Figure 1.3. June 1997 flooding of Interstate 43 in northern Milwaukee metropolitan area. The event causing flooding was greater than 100 year storm. The capacity of an inverted siphon conveying a small suburban stream under the freeway was insufficient to handle the flow increased by urbanization.

Ecological and Water Quality Changes

Ecology of a stream needs to be seen more than the stream channel alone. A stream is a corridor that consists of three major components:

- ! Stream channel
- ! Floodplain
- ! Transitional upland fringe.

Water and other material, energy, and organisms meet and interact within the corridor over space and time. The ecological integrity of a stream is made up of three components: physical, chemical, and biological (Plafkin *et al.*, 1989). EPA defines “ecological integrity” as “*the condition of the aquatic community inhabiting unimpaired water bodies of a specific habitat as measured by community structure and function*”. Physical integrity is achieved when the stream provides the needed physical habitat structure for the biological community. Chemical integrity involves providing the needed water quality conditions for the organisms such as adequate dissolved oxygen and nutrients and toxic compounds below the threshold of an adverse impact upon the organisms.

Flow regime and flow magnitudes have impact both on flooding and on the integrity of the streams. Since the hydrological balance of the stream is modified by urbanization an analysis should be made to establish the effect of the hydrological changes on the integrity of the stream impacted by urbanization.

1. *Low flow* may result in high concentrations of pollutants in the water body because not enough flow is available to dilute steady point source and contaminated base flow pollutant loads. These flows with a magnitude that is significantly smaller than the average annual flow, occur after a period of drought and do not contain wet weather contributions. Such flows have no physical erosive effect on habitat, however, deposition of solids from untreated or partially treated effluents that impairs benthic organisms may be significant. This deposition adversely affects the embeddedness of the bottom substrate and may increase the sediment oxygen demand of the sediments. The most adverse impact of sedimentation of fine grained and organic sediments occurs in impoundments..

Urbanization also diminishes the magnitude of natural small (base) flow. Some streams became ephemeral following urbanization, which is devastating to the ecology of the stream, or the aquatic life can be sustained only by steady treated effluent discharges (effluent dominated streams). Pollution control should focus on dry weather point sources.

2. *Medium flows* (between mean annual flow and average annual high flow, i.e., wet weather flows with a recurrence interval of less than one year. Typically, these are rain (storm) water and snowmelt flows originating primarily from impervious urban surfaces directed towards the receiving waters by storm sewers and combined sewer overflows. They include highly polluted washoff from streets, highways and sewers, and snowmelt laden with deicing chemicals. Contributions from pervious surface are typically small or none. These flows may contain the highest concentrations of toxic chemicals that may be greater than those measured during very low flows. The physical effects on channel erosion and habitat may be small. Deposition of solids may occur only in pools, impoundments or estuaries. Because these flows have a recurrence interval of less than three years they are significant for water quality considerations and ecology. Pollution control should rely on quality control best management practices.
3. *Medium high flows* (flows that have a recurrence interval between one to three years). The highest concentrations of pollutants may actually occur during medium flows if wet weather pollutant loads (storm and combined sewer overflows) are present. As pointed out in the preceding sections, these flows also are crucial for channel and channel bank stability. If the one to two year flows are substantially greater than the channel bankfull flow (channel capacity), channels become unstable and habitat conditions deteriorate. These flows are also responsible for loads of suspended solids from surface erosion (both urban/construction and rural/agricultural) that may silt the channel bottom and damage habitat for benthic organisms

in impounded section of the receiving water body. Because these flows have a recurrence interval of less than three years they are significant for water quality and ecology.

Best management practices used to control the adverse impacts of the medium high flows should include both flow volume and quality controls.

4. *Extremely high flow* (recurrence interval greater than ten years). These flows cause a majority of flood damages. In some urbanized sections, flooding may occur with a higher frequency, as documented on Figure 1.2, due to the increase of the magnitude of high flows and insufficient channel capacity.

Best management practices should focus on peak flow controls and floodplain management. Water quality control is not relevant for the practices that function only infrequently.

Much of the past control efforts have focused on the control of peak flows during large flood events to protect downstream property. In recent years, some communities have begun to implement stormwater practices to trap stormwater pollutants and address water quality issues. Generally, the state of the art of urban stormwater management is far ahead of the “state of the practice” (Walesh, 1989).

Stormwater management practices can be divided into many categories ranging from those that address stormwater quantity to those that address stormwater quality. For the purpose of this paper, stormwater practices will be broken down into the following three categories:

- Source Controls
- Volume Reduction Alternatives
- Stormwater Storage and Treatment Alternatives

Source controls are those practices that address water pollutants at their source and attempt to prevent them from entering the runoff stream. Source controls address water quality issues but typically provide limited flood control relief. Volume reduction alternatives address the quantity of runoff through practices such as infiltration. Since the amount of pollutants generated off the land surface is directly proportional to the quantity of runoff, reducing the volume of stormwater flow also reduces the quantity of pollutants. Stormwater storage and treatment alternatives include practices that detain stormwater runoff and allow potential removal of the pollutants.

The purpose of this the report is to provide an overview of the available stormwater management practices and their water quality, ecological, and flood control benefits. Water quality benefits will be defined predominately in the form of pollution control. Ecological benefits will include in-stream habitat protection. This report provides an overview of how each of the management practices work, general design criteria required to function properly, and the individual benefits each practice provides.

CHAPTER 2

SOURCE CONTROL BEST MANAGEMENT PRACTICES

Source controls act to control pollutants before they become part of the runoff stream. By keeping the pollutants out of the stormwater, they do not contribute to downstream contamination. Source controls include such practices as construction site erosion control, street sweeping, fertilizer management, litter control, and pet waste control.

Construction Erosion Control Alternatives

Construction site erosion is a major source of sediment in urban streams. Construction activities enhance the potential for soil erosion by exposing bare soil to rainfall and runoff processes. It is estimated that soil erosion from construction sites, such as new development and highways, can equal or exceed 30 tons/acre/year (WDNR, 1992). The amount of increase in sediment yield is directly related to the construction area/drainage area ratio (Chen, 1974). As the exposed soil is replaced with impervious and landscaped surfaces the rate of erosion declines typically to levels as low or lower than those prior to construction (Wolman, 1967).

The process of soil erosion can be defined by the *Universal Soil Loss Equation* (USLE) developed by the Agricultural Research Service of the U.S. Department of Agriculture. The USLE formulated by Wischmeier and Smith (1965) predicts sheet and rill erosion by use of the following equation:

$$A = (R)(K)(LS)(C)(P)$$

where:

- A = calculated soil loss in tons/acre for a given period
- R = rainfall energy factor
- K = soil erodibility factor
- LS = slope-length factor
- C = cropping management (cover) factor
- P = erosion control practice factor

The equation expresses soil loss per unit area due to erosion by rain. The R factor has the units of tons/acre or tonnes/ha. Each other factor in the equation is a ratio number that increases or decreases the erosion rate depending on site conditions.

The construction process dramatically effects two components of the USLE equation, the cropping management (vegetative cover) factor (C) and the erosion control practice factor (P). Table 2.1 summarizes some typical C and P factors for construction sites. Novotny and Olem (1994) provide a more complete list of factors..

Typical erosion control practices include practices such as siltation barriers, sedimentation basins, storm sewer inlet protection, temporary rock construction entrances, diversions, and seeding and mulching. Based on the C and P factors in Table 2.1, it can be seen that a small sedimentation basin or a silt fence provide only a 30 to 50% reduction in soil erosion. However, the use of a temporary seeding with straw mulch can provide up to a 90% reduction in soil loss, illustrating the importance of soil cover in the erosion process.

TABLE 2.1
Selected list of C and P factors for construction sites

Condition	C-factor
Bare soil, no mulch or seeding	1.0
Straw or hay tied down by anchoring or tracking	0.06 to 0.12
Crushed stone	0.02 to 0.05
Temporary seeding, no mulch	0.10
Temporary seeding, straw mulch (3.4 tonnes/ha)	0.05
Sod	0.01
Condition	P-factor
Compact, smooth, scraped with bulldozer or scraper up and down hill	1.30
Compact, smooth, scraped with bulldozer or scraper across hill	1.20
Loose as a disked plow layer	1.00
Sedimentation basin (0.09 ha basin/ha)	0.50
Sedimentation basin (0.12 ha basin/ha)	0.30
Silt fence	0.70 to 0.50

Source: Ports (1973, 1975)

Water Quality Impacts

Use of construction site erosion control practices can dramatically prevent increases of total suspended solids levels in the receiving water bodies. Other contaminants such as nutrients attached to the soil particle are also controlled by erosion control practices.

Ecological Impacts

Reed (1977) in a study of a Virginia stream following a highway construction project, found a 23% reduction in species and 66% reduction in number of aquatic organisms. Preventing sediment from entering a stream will prevent smothering of organisms, damage to gill tissue, embeddedness of bottom sediment, and loss of aquatic habitat.

Flood Control Impacts

Erosion control practices provide limited flood control benefits. The reduction in sediment in the stream channel reduces the area of the channel cross-section that is consumed by carrying sediment. Less sediment deposits in the channel results in less channel blockage by vegetation such as cattails and shrubs. Vegetated soil provides more surface detention that helps retain water and encourages infiltration, thereby reducing runoff volumes. Table 2.2 illustrates a comparison of the runoff depth for vegetated and bare soil for a 10-year 24-hour storm using the SCS curve method. As can be seen, vegetation can reduce the volume of runoff during a 10-year storm between 29 and 84% depending on the soil type.

TABLE 2.2
Comparison of runoff depth for Vegetated and bare soil for a 10-year 24-hour storm

Soil Hydrologic Group	Bare Soil		Vegetated Soil ¹		Percent Reduction Caused by Vegetation
	Curve Number	Runoff Depth (mm)	Curve Number	Runoff Depth (mm)	
A	77	46.0	49	7.6	83.5%
B	86	64.7	69	32.2	50.3%
C	91	76.6	79	49.9	34.9%
D	94	84.4	84	60.2	28.7%

¹ Grass in fair condition

Street Sweeping

Street sweeping involves the removal of dust, debris, and trash from parking lots and street surfaces. Streets are normally swept with either mechanical broom or vacuum sweepers. The theory behind pollution control by street sweeping is that if the materials are removed from the streets where they are deposited, they are no longer available to be transported by surface runoff. In most communities, street sweeping is done for aesthetics and urban housekeeping rather than pollution control. Unlike many urban nonpoint source control measures, street sweeping can be readily applied to existing urban areas without any physical disturbance or change to the landscape.

Water Quality Impacts

Street sweeping is most effective for the removal of coarse particles, leaves, trash and other similar materials. Studies have shown that most of the pollutants on street surfaces with curbs and gutters are located within 1 meter of the curb (Bannerman et al., 1984). Pollutants on the street surface are redistributed along the curb by wind turbulence generated from automobile traffic. The curb acts as a barrier, trapping pollutants blown off the center of the street by the cars. In areas without a curb, much of the pollution mass is blown out into adjacent grass areas. Therefore, for street sweeping to be effective on streets, the street must have a curb. Pollutants reduced by street sweeping include sediment, nutrients, and oxygen demanding compounds (MPCA, 1989).

The effectiveness of street sweeping is a function of the type of equipment, effectiveness of the operator, presence or absence of parked cars along the curb, time of the year, traffic volumes, and frequency of sweeping. Table 2.3 outlines the effectiveness of street sweeping for the removal of sediment based on sweeping frequency in Milwaukee, Wisconsin.

It can be seen that street sweeping using traditional sweepers does not remove sufficient sediment quantities in residential areas to be effective as a pollution control practice. Sweeping in commercial and industrial areas can provide some pollution reduction, however, sweeping frequencies of at least 4 times per month (once per week) are required for any reasonable level of control. Street sweeping in the fall when large amounts of leaves are on the street surface, and in the spring following winter accumulation of particulates and prior to heavy spring rains, provide the greatest pollutant removal efficiencies per sweeping. Street sweeping in the summer months is not as effective in most areas of the country because frequent rainstorms typically remove the pollutants from the street prior to the sweeping operation.

TABLE 2.3
Sediment removal effectiveness of street sweeping

Land Use	Percent Sediment Removal by Frequency of Street Sweeping (Times Per Month)			
	0.3	1.0	2.0	4.0
Low Density Residential	<1%	1%	2%	3%
Medium Density Residential	<1%	1.5%	2%	4%
High Density Residential	<1%	1%	2%	3.5%
Commercial	10%	26%	35%	47%
Industrial	7%	9%	20%	28%

Source: SEWRPC, 1991

Tests are being conducted on several new lines of “high efficiency” sweepers. These new sweepers are designed to pick up smaller particle sizes and more contaminants off the pavement surface. Preliminary results of the equipment’s efficiencies are outlined in Table 2.4.

TABLE 2.4
Preliminary results of efficiency tests on high efficiency sweepers

Land Use	Percent Sediment Removal by Frequency of Street Sweeping Using High Efficiency Sweeper (Times Per Month)		
	1.0	2.0	4.0
Residential	51%	63%	79%
Arterial Road	49%	62%	76%

Source: (Sutherland, et al 1998)

Ecological Impacts

Due to low efficiency of traditional brush and vacuum street sweeper, the ecological benefits of this alternative are limited.

Flood Control Impacts

Street sweeping provides no impacts on flood elevations or peak rates of surface water runoff.

Fertilizer Management

A source of phosphorus and nitrogen in the runoff from landscaped surfaces can be the excessive use of lawn fertilizers. Fertilizer management involves the control of the rate, timing, and method of

fertilizer application in urban areas so the excess nutrients do not contaminate the surface or groundwater. By applying fertilizers at rates that are proportional to the lawn's needs, excess nutrients are not available to be removed by the runoff.

The following is a list of recommendations for safe fertilizer application:

1. Have the soil tested for its nutrient needs and follow the recommendations of the test. In most states the University Extension provides soil testing at a nominal fee through the local County Extension Office.
2. Apply fertilizer in several small applications throughout the summer instead of applying the entire dose for the year in one application. Never apply more than is recommended on the manufacturer's label.
3. Leave grass clippings on the lawn. This is equal to one fertilizer application per year.
4. Water the lawn after fertilizing, but do not allow the water to runoff into the ditch or street.
5. Any fertilizer spilled on roads or sidewalks should be promptly cleaned.
6. Never apply fertilizer to frozen ground.
7. Leave a buffer strip along ditches, waterways and ponds that is not fertilized.

Water Quality Impacts

Table 2.5 presents the results of a four-year study conducted in Madison, Wisconsin on the runoff from three land use areas (Bannerman et al., 1993). The results show that for areas with a large percent of the land cover in lawns, the turf can be a significant source of phosphorus. Based on the limited monitoring data available, it is not possible to evaluate the total effectiveness of fertilizer management on downstream water quality.

TABLE 2.5
Results of monitoring for total phosphorus (TP) from
three watersheds in Madison, Wisconsin

Land Cover	Syene Industrial Park		Monroe Residential Area		Monroe Commercial Area	
	% Land Cover	% TP Loading	% Land Cover	% TP Loading	% Land Cover	% TP Loading
Roofs	21	6.5	12	0.7	20	5.9
Parking Lots	33	44.2	1	0.2	44	18.9
Driveways	1	<1	5	20.2	0	0
Streets	7	29.9	13	44.4	35	72.3
Sidewalks	0	<1	3	<1	1	3.0
Lawns	38	19.4	66	34.4	0	0

Source: Bannerman et al., 1993

Ecological Impacts

Reductions in phosphorus levels due to fertilizer management may result in less stream eutrophication. Due to lack of monitoring, data the degree of benefits is unknown.

Flood Control Impacts

Fertilizer management provides no impacts on flood elevations or peak rates of surface water runoff.

Litter Control

Litter control involves the removal of leaves, grass clippings and other debris from hydraulically active areas such as curbs and waterways. It has been estimated that an average tree drops 14.5 to 26 kilograms of leaves per tree per year (Novotny and Chesters, 1981). The leachate from leaves and lawn clippings is a source of phosphorus in urban runoff. Preventing these materials from being placed in an area where can be washed away can reduce phosphorus loadings. The following is a list of recommendations to control litter in urban areas:

1. Do not stockpile leaves or grass clippings in hydraulically active areas such as curbs, roadside ditches, or backyard waterways.
2. Wherever possible, leaves and grass clippings should be composted in an area away from waterways.
3. Leaves should not be burned in road side ditches where the ash can be washed away.
4. Lawn clippings blown onto streets, parking lots and/or driveways should be removed to prevent them from washing away.

Water Quality Impacts

Large inputs of organic solids from leaves and lawn clippings can produce the following water quality impacts (Richards, 1995):

- Decreased dissolved oxygen levels
- Increased stream eutrophication caused by excess nitrogen and phosphorus
- Increased pesticide levels from material attached to organic material

Therefore, control of leaves and vegetation can minimize these problems.

Ecological Impacts

The ecological impacts of litter control are both positive and negative. Decreased dissolved oxygen levels can result in reduced diversity and numbers of aquatic organisms. However, many urban streams are starved for coarse organic matter used by many macroinvertebrates. The loss of vegetated riparian corridors in many urban streams makes leaves and other organic debris from the watershed the only source of organic material.

Flood Control Impacts

Litter control provides no impacts on flood elevations or peak rates of surface water runoff.

Pet Waste Control

Pet waste can be a source of fecal bacteria, nutrients, and oxygen demanding compounds in urban runoff when allowed to be deposited on sidewalks or street surfaces. To control pet waste, the owner should pick up any material deposited by their pet and dispose of it in a proper manner by placing it in the garbage, flushing it down the toilet, or burying it in the backyard. To prevent the potential spread of disease, pet waste should not be placed in compost piles where the compost will be used on vegetable gardens (UW-EXT, 1994). Many communities have ordinances that regulate pet waste and require proper disposal of the waste by pet owners.

Water Quality Impacts

Fecal coliforms, a bacteria that inhabits the digestive system of warm blooded animals, has been found in urban runoff at levels of greater than 1,000,000 counts per 100 ml (Bannerman et al., 1993). The event mean concentration (EMC) from the NURP project, measured at 17 different sites, was 21,000/100 ml (U.S. EPA, 1983). Sources of these bacteria can include wild animals, sanitary sewer cross connections, and pet waste. In a study in Baltimore, Maryland, (Olivieri et al, 1977) 95% of the 136 samples were found to be positive for Salmonella.

Ecological Impacts

The ecological impacts of high in-stream fecal bacterial levels is not documented in the literature.

Flood Control Impacts

Pet waste control provides no impacts on flood elevations or peak rates of surface water runoff.

CHAPTER 3

FLOW VOLUME REDUCTION ALTERNATIVES

Figure 3.1 shows an overview of the hydrological cycle. In undeveloped watersheds with minimum impervious area (usually less than 5 percent), infiltration can account for as much as 50% of the hydrologic budget, helping maintain runoff levels as low as 10%, and replenishing both the shallow and deep groundwater tables (MPCA, 1989). As the area develops, the amount of infiltration is decreased as rainfall is captured by impervious surfaces. In areas with 75 to 100% imperviousness, infiltration can be reduced to as low as 15% of the water budget, with 50% or more of the rainfall becoming runoff.

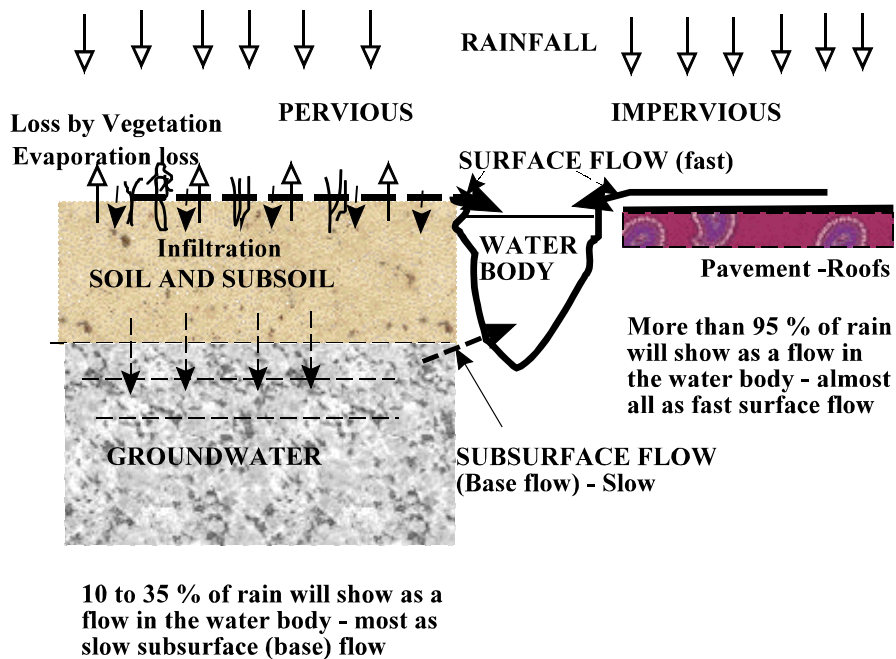


Figure 3.1 Concept of infiltration in urban and urbanizing areas.

Infiltration rates are a function of the soil characteristics and saturated conditions. Equations used to define the rate of infiltration under different water loading and saturation conditions include the Horton's formula, Holtan's formula, Philip's equation, and Green-Ampt equation. These equations were summarized in Novotny and Olem (1994).

The amount of pollutants generated off the land surface is directly proportional to the quantity of runoff. Reducing the volume of stormwater flow can reduce the quantity of pollutants.

The only way to reduce the volume of runoff is to move more of the rainfall into either evapotranspiration or infiltration. Since evapotranspiration is controlled predominately by atmospheric conditions and it is insignificant during high humidity conditions during rainfalls, it is

not a realistic method of control from a management standpoint. Therefore, infiltration is the only feasible method of controlling stormwater volumes. Stormwater runoff can be captured and infiltrated into ground surface when sub-soil conditions are adequate.

Infiltration systems combined with vegetated surfaces can enhance the pollutant removal process by allowing changes in flow hydraulics that enhance deposition of suspended solids, filtration of suspended solids by vegetation, absorption to plant and soil surfaces, and absorption of soluble pollutants by plants

Methods to encourage infiltration of stormwater runoff include infiltration basins, infiltration trenches and dry wells, porous pavement, grass swales, filter strips and stream buffers.

Infiltration Basin

An infiltration basin is a water impoundment constructed over permeable soils. The purpose of the basin is to temporarily store surface water runoff from a specific design storm and allow it to infiltrate through the bottom and sides of the basin. Pollutants are removed by the filtering action of the soil. Infiltration basins also provide for groundwater recharge, reduced volumes of runoff, and reduced peak discharges.

For infiltration basins to be feasible, the sub-soils needs to have an infiltration rate of 0.7 cm/hour (0.27 inches per hour) or greater (MPCA, 1989). This corresponds to soils in the A and B hydrologic soil classification which includes silt loam, loam, sandy loam, and sandy soils.

The potential for groundwater contamination is an obvious concern when planning an infiltration basin. The basin should be designed to have a 2 to 4 foot separation between the bottom of the basin and the water table. Studies of five infiltration basins conducted by the National Urban Runoff Project (NURP) have found that soil beneath the basins effectively traps the pollutants and that no significant groundwater contamination was taking place (MPCA, 1989). However, infiltration basins should not be used to treat runoff that may contain large quantities of very soluble pollutants, such as nitrates or pesticides like diazinon.

Infiltration basins need to drain down and dry out in a reasonable period of time to prevent sealing of the bottom by a slime layer of algae, bacteria and fungus. If water is allowed to sit in the bottom of the basin more than 72 hours in most climates, the conditions to allow slime formation is high. The following formula can be used to calculate the maximum allowable ponding depth in a basin to achieve a given design ponding time:

$$\mathbf{d_{max} = (f)(T_p)}$$

Where:

- d_{max} = Maximum design depth (cm or inches)
- f = Soil infiltration rate (cm/hr or inches/hour)
- T_p = Design ponding time (hours)

To maintain the infiltration capacity of the basin, it is important that excessive sediment loadings are avoided. Studies in the State of Florida have found that infiltration basins with grass bottoms tended

to perform longer than basins with earthen bottoms. A potential reason for the improved performance of grass bottom basins may be that the organic debris of the grass provides habitat for burrowing insects and worms that assist in naturally keeping the soil aerated, thereby maintaining infiltration capacity of the upper soil layer.

General guidelines for the design of infiltration basins are summarized in Table 3.1.

Table 3.1.
Guidelines for infiltration basin design

Design Parameter	Design Criteria
Drainage area range	2 to 20 ha (5 to 50 acres)
Minimum infiltration rate	0.7 cm/hr (0.27 inches/hour)
Maximum ponding time	72 hours
Inlet control	Pre-filtration of settleable solids

Source: (MPCA), 1989)

Maintenance needs include inspections annually and after large storms, mowing at least twice a year, debris removal, erosion control and control of nuisance odor or mosquito problems. Deep tilling may be needed at 5 to 10 year intervals to break up a clogged surface layer. The tilled surface would then need to be graded and revegetated. In some cases an underdrain pipe may be needed to maintain adequate drawdown conditions. Accumulated sediments may also have to be removed by light equipment.

Water Quality Impacts

Table 3.2 outlines typical long-term pollutant removal rates for infiltration basins and trenches. While properly designed infiltration basins can reduce pollutant discharges to surface waters, they can act to divert the pollutants into the groundwater system (Milkkelsen et al , 1994; Milkkelsen et al , 1997). The potential for groundwater contamination depends on the stormwater sources, subsoil characteristics, and degree of concentration of the runoff into a limited area. Pitt et. al. (1996) conducted a review of potential contaminants found in urban runoff and their potential to contaminate groundwater. Table 3.3 summarizes the results of Pitt’s review.

Ecological Impact

Impacts of reductions in stormwater runoff rates and pollutant loadings through the increase in infiltration, may includes the following:

- ! Increased stream base flow
- ! Reduced in-stream velocities
- ! Decreased streambed scour
- ! Decreased channel and bed erosion
- ! Decreased embedded sediments

TABLE 3.2
Typical long-term pollution removal rates for
infiltration trenches and basins (Schueler, 1987)

Pollutant	Typical Removal Rates
Sediment	75-90%
Total Phosphorus	50-70%
Total Nitrogen	45-60%
Biological Oxygen Demand	70-80%
Metals	75-90%
Bacteria	75-90%

TABLE 3.3
Potential stormwater pollutants that may contaminate groundwater (Pitt et al, 1996)

Category	Potential Pollutant	Abundance in Stormwater	Potential for Groundwater Contamination Without Pretreatment
Nutrients	Nitrate	Low/moderate	Low/moderate
Pesticides	Lindane	Moderate	Moderate
	Chlordane	Moderate	Moderate
Other Organics	1,3dichlorobenzene	High	Low
	Pyrene	High	High/moderate
	Floranthene	High	Moderate
	Benzo(a)anthracene	Moderate	Low/moderate
	Bis (2-ethylexyl) phthalate	Moderate	Low/moderate
	Pentachlorophenol	Moderate	Low/moderate
	phenanthrene	Moderate	Low/moderate
	VOC's	Low	Low
Pathogens	Entroviruses	Present	High
	<i>Shigella</i>	Present	High
	<i>Pseudomonas aeruginosa</i>	High	High/moderate
	Protozoa	Present	High/moderate
Heavy metals	Nickel	High	High
	Zinc	High	High
	Chromium	Moderate	Moderate
	Lead	Moderate	Moderate
Salts	Chloride	Seasonally high	High

- ! Maintenance of stream geomorphology
- ! Reduced water temperatures
- ! Increased dissolved oxygen levels
- ! Reduced pollutant toxicity

Flood Control Impacts

The flood control benefits of infiltration basins may include the following:

- Reduced peak flood flows
- Reduced stormwater runoff volumes
- Reduced duration of flood flow
- Increased channel capacity to carry flows from upstream watershed areas

The degree of benefits from any infiltration practice will depend on the percentage of the runoff volume captured by the infiltration system.

Infiltration Trenches

A conventional infiltration trench is a shallow, excavated trench that has been backfilled with stone to create an underground reservoir. Stormwater runoff diverted into the trench gradually exfiltrates from the bottom of the trench into the subsoil and eventually into the water table. Stormwater is treated by the soil adjacent to the trench. Infiltration trenches work similar to infiltration basins and have similar pollutant removal capacities. General guidelines for the design of infiltration trenches are summarized in Table 3.4.

TABLE 3.4
Guidelines for infiltration trench design

Design Parameter	Design Criteria
Drainage area range	0.8 to 2 ha (2 to 5) acres
Minimum infiltration rate	0.7 cm/hr (0.27 inches/hour)
Min. separation from groundwater	0.6 to 0.9 m (2 to 3 feet)
Inlet control	Pre-filtration of settleable solids

Source: MPCA (1989), Schueler, et.al. (1991)

Enhanced infiltration trenches need extensive pretreatment systems to remove sediment and oil. They require on-site geotechnical investigations to determine appropriate design and location.

Maintenance includes inspections annually and after large storms, buffer strip maintenance and mowing, and rehabilitation of the trench when clogging begins to occur. Surface clogging can be

relieved by replacing the top layer of the trench but bottom clogging requires the removal of all of the filter and stone aggregate.

Water Quality Impacts

Similar to those for infiltration basins.

Ecological Impacts

Similar to those outlined under infiltration basins.

Flood Control Impacts

Similar to those outlined under infiltration basins.

Porous Pavement

Porous pavement is an alternative to conventional pavement whereby runoff percolates through a porous surface layer into an underground gravel subbase/reservoir. Porous pavements can provide for stormwater storage and enhanced infiltration. The stored runoff in porous pavement gradually infiltrates into the subsoil or is drained away either by a subdrain system or directly into a permeable subsoil. The pavement is either made from asphalt, in which the fine filler fractions are missing, or modular or specially poured concrete.

General guidelines for the design of porous pavement are summarized in Table 3.5.

TABLE 3.5
Guidelines for porous pavement design (Schueler et.al., 1991)

Design Parameter	Design Criteria
Drainage area range	Maximum 4 ha (10 acres)
Minimum infiltration rate	1.2 cm/hr (0.5 inches/hour)
Min. separation from groundwater	0.5 to 0.9 m (2 to 3 feet)
Maximum pavement slope	5 percent
Maintenance	Frequent vacuum sweeping to fine sediment

Porous pavements can easily become clogged with fine sediment. Therefore, they are not recommended for high traffic areas. Frequent cleaning with vacuum-type street sweeping equipment is required.

Water Quality Impacts

Pollutant removal using porous pavement, based on two monitoring studies, has been shown to control 80% of suspended sediment, 60% of the total phosphorus, 80% of nitrogen, and high levels of trace metals and organic matter (Schueler, et.al., 1991).

Ecological Impacts

The ecological benefits of porous pavement are similar to those outlined under infiltration basins. However, since porous pavements are limited to low traffic areas, wide spread use of the practice in most urban watersheds is limited. Therefore, the ecological benefits of this practice are likely limited.

Flood Control Impacts

Results from a study in Rochester, New York, indicated that peak runoff rates were reduced by 83% when porous asphalt was used (Field, 1986). Hydraulic conductivity of porous pavements have been measured to be greater than typical rates of storm rainfall intensity. Hydraulic conductivity measured by Jackson and Ragan (1974) was about 250 cm/hr, indicating that properly installed porous pavement can infiltrate 100 percent of most design storms without causing surface ponding. However, again, since porous pavements are limited to low traffic areas, the use of the practice on a wide spread basis in most urban watersheds is limited, therefore, the large scale flood control benefits of this practice are likely limited. Porous pavement may have the best beneficial impact for control of runoff during medium storms.

Grassed Swales

Conventional grassed swales or waterways are vegetated earthen channels that convey stormwater. Swales remove pollutants from urban stormwater runoff by filtration through the grass and infiltration through soil (Ferguson, 1994). The filtering capacity of the vegetation is dependent on the depth of flow. Typically, when the flow depth is above the top of the vegetation, filtering is minimal.

For a grass swale to be effective, Minnesota Pollution Control Agency (MPCA, 1989) recommended that it should be constructed as a broad, wide channel with side slopes of no greater than 3:1 and a grade no greater than 2 percent. To prevent channel erosion, the velocities in the swale should not exceed (0.9 to 1.8 m/s (3-6 feet per second) (Goldman, et.al., 1986). To maximize the potential for infiltration, velocities should not exceed 0.6 m/s (2 feet per second) for the design storm. For effective pollutant control, the depth of the channel should not be greater than 0.3 to 0.45 m (12 to 18 inches). To maintain proper drainage, grass swales should not be constructed with less than 1.5% grade.

The length of a triangular cross-sectional channel necessary to infiltrate all of the stormwater from a design storm can be calculated from the following equation (Wanielista and Yousef, 1993):

$$L = \frac{K Q^{0.63} S^{0.19}}{n^{0.38} f}$$

Where: L = length of swale, m or ft
 Q = average runoff flow rate, m³/s or ft³/s
 S = longitudinal slope, m/m, ft/ft
 n = manning roughness coefficient
 f = infiltration rate, cm/hr or in/hr
 K = side slope constant.

Enhanced grassed swales, or biofilters, utilize check dams and wide depressions to increase runoff storage, promote greater settling of pollutants, and allow water to be stored to facilitate infiltration. The volume of storage that can be provided by berms in a grass swale can be calculated using the following formula (Wanielista and Yousef, 1993):

$$V_b = L/3 (A + a + A_a)$$

Where: V_b = volume at end of berm with an upstream berm, m³ or ft³
 A = cross-sectional area at berm, m² or sq ft
 = $WH/2$
 W = width of swale water line at the crest of the berm, m or ft
 a = cross-sectional area upstream of berm if obstructed upstream, m² or ft²
 = $wh/2$
 w = width of swale water line upstream, m or ft
 h = height of swale water line upstream, m or ft

Maintenance activities for grassed swales include clearing of debris, periodic mowing, spot reseeding or resodding, weed control and watering during drought. Grass height should remain six inches or higher in order to filter runoff and slow down flow velocities. Application of pesticides and fertilizers should be minimized.

Water Quality Impacts

Typical pollutant removals for grass swales are outlined in Table 3.6.

Ecological Impacts

The ecological benefits of grass swales are similar to those outlined under infiltration basins and will be limited to predominately small storms.

TABLE 3.6
Percent pollutant load reduction by grass swales

Pollutant	Study						
	Seattle (1992)		Florida (1988)		Virginia (1989)	Maryland (1989)	Florida (1989)
			wet	Dry			
Swale length (ft)	100	200	230	230	185	193	185
Suspended sediment	60	83	81	87	65	(-85)	98
Total phosphorus	45	29	17	83	41	12	18
Total lead	15	67	50	90	41-55	18-92	67-94
Total zinc	16	63	69	90	49	47	81
Total copper	2	46	56	89	28	14	62-67
Total aluminum	16	63					
Total cadmium			42	89	12-98	85-91	29-45
Total chromium			37	88	12-16	22-72	51-61
Nitrate	neg.	neg.	52	80	11	(-143)	45
TPH (hydrocarbons)	49	75					
Organic carbon					76	23	64

Source:(Seattle METRO (1992), Harper (1988), Dorman, et.al. (1989).

Flood Control Impacts

Infiltration in grass swales is limited to predominately small storms (WEF & ASCE, 1998). Therefore, the flood control benefits of grass swales will be dependent on infiltration rates, percent of drainage area captured in the swale, soil saturation levels, and size of the storm event. Grass swales will likely provide very limited to negligible reductions in volumes and peak flows during large flood events, such as a 50- or 100-year storm.

Filter Strips

Filter strips are vegetated sections of land designed to accept runoff as overland sheet flow from upstream development. They may adopt any natural vegetated form, from a grassy meadow to a small forest. The dense vegetative cover facilitates pollutant removal. In areas of A and B soils, filter strips can facilitate infiltration. Filter strips cannot treat high velocity flows. Therefore, they are generally used for small drainage areas. Grass filter strips provide higher pollutant removal rates than grass swales. Filter strips differ from grassed swales in that swales are concave vegetated conveyance systems, whereas filter strips have fairly level surfaces.

General guidelines for grass filter strips are outlined in Table 3.7.

TABLE 3.7
Guidelines for grass filter strip design

Design Parameter	Design Criteria
Filter width	Minimum width 15 to 23 meters (50 to 75 feet), plus additional 1.2 meters (4 feet) for each 1% slope.
Filter slope	Maximum slope of 5%.
Flow velocity	Maximum flow velocity of 0.75 m/s (2.5 fps).
Grass height	Optimum grass height of 15 to 30 cm (6 to 12 inches).
Flow distribution	Should include a flow spreader at the upstream end to facilitate sheet flow across the filter.

Source: (MPCA, 1989) (Novotny and Olem, 1994).

Dense grass needs to be maintained in filter strips and gully and channel formation should be prevented. Spot repairs of the turf along with watering and fertilization may be needed. Grass heights should remain at six inches or greater. Pesticide and fertilizer use should be limited to the minimum necessary for dense growth.

Water Quality Impacts

The rate of pollution removal in filter strips is a function of the length, slope, soil, and permeability of the filter strip. Strips are effective in removing sediment and sediment associated pollutants such as bacteria, particulate nutrients, pesticides and metals. Infiltration is an important removal mechanism in filter strips. Many pollutants, including phosphorus, are dissolved or associated with very fine particles that move into the soil with infiltrating water. Once in the soil profile, the pollutants are trapped by a combination of physical, chemical, and biological processes. Infiltration is also important because it decreases surface runoff, which in turn reduces the ability of runoff to transport pollutants.

In a study of grass filter strips conducted by Lee, et al (1989), it was concluded that removal of sediment and nutrients from surface water by filter strips is primarily the result of the infiltration of dissolved nutrients and reductions in sediment transport capacity caused by decreased water volume and increased resistance to overland flow. Sediment deposition was determined to be the major trapping mechanism for phosphorus removal by buffer strips. Increased infiltration in buffer areas is ascribed to flow retardation due to increased surface roughness caused by vegetation and good soil aggregation due to increased soil organic matter. It was determined that biological uptake of nutrients during single events was negligible.

At least a 40% removal of sediment can be expected from strips as narrow as 7.5 meters (25 feet), and strips 27 to 90 meters (90 to 300 feet) wide may remove all of the sediment load, depending on the soil permeability and sediment source (SEWRPC, 1991).

The distance at which 100% of the sediment is removed by a filter strip is called the "critical distance" (Novotny and Olem, 1994). In a study using Bermuda grass, 100% of the sand, silt and clay were removed in distances of 3 meters (10 feet), 15 meters (45 feet), and 120 meters (400 feet) respectively (Wilson, 1967).

The efficiency of a filter strip has been found to be a function of the submerged flow Reynolds number, Re_s , and the particle fall number, N_f (Barfield, Kao and Toller, 1975; Toller et al., 1977). The methodology for calculating/designing grassed filter strips is outlined in Novotny and Olem (1994).

Ecological Impacts

The ecological benefits of filter strips are similar to those outlined under infiltration basins and will be limited to predominately small storms.

Flood Control Impacts

Infiltration in filter strips is limited to predominately to small storms (WEF & ASCE, 1998). Therefore, the flood control benefits swales will be dependent on infiltration rates, percent of drainage area captured in the swale, soil saturation levels, and size of the storm event. Grass swales will likely provide only minor or no reductions in volumes and peak flows during large flood events, such as a 50- or 100-year storm.

Stream Buffer Strips

Riparian stream buffers are a high breed of filter strips. Typically located in the floodplain they function to treat stormwater in two ways. During small storm events the stream buffer act a filter strip, filtering water from the adjacent watershed as it moves towards the stream. During flood events, water from the river over tops the bank and spreads out over the buffer, allowing suspended sediment to be deposited and some infiltration to take place.

Water Quality Impacts

Pollutant removal mechanisms associated with stream buffers strips involve changes in flow hydraulics that enhance infiltration, deposition of suspended solids, filtration of suspended solids by vegetation, absorption to plant and soil surfaces, and absorption of soluble pollutants by plants (Lee, et al, 1989). For the above mechanism to be effective, flow through the buffer must be slow and shallow.

As with filter strips, infiltration is an important removal mechanism in stream buffers. Many pollutants, including phosphorus, are dissolved or associated with very fine particles that move into the soil with infiltrating water. Once in the soil profile, the pollutants are trapped by a combination of physical, chemical, and biological processes. Infiltration is also important because it decreases surface runoff, which in turn reduces the ability of runoff to transport pollutants.

Stream buffers also purify runoff through the process of deposition. Because stream buffers are usually composed of grasses and other dense vegetation, which offer high resistance to shallow overland flow, they decrease overland flow velocities immediately up-slope of the and within the

buffer. As streams over top their banks and spread their flow across the stream buffer, deposition of suspended sediment loads also takes place. This reduces sediment transport capacity. If the resulting sediment transport capacity is less than the load of suspended solids, the excess is deposited and trapped in the buffer. Sediment bound pollutants, such as phosphorus, will be removed during the deposition process.

The filtration of suspended solids by vegetation during overland flow and the adsorption and absorption process are not as well understood as infiltration and deposition processes (Lee, et al, 1989). Filtration is probably most significant with larger suspended solid particles, while adsorption and absorption probably more significant with respect to removal of dissolved solids.

Cooper et al (1987) monitored two small watersheds to determine the sediment and nutrient removal efficiencies of stream buffers. Copper found that stream buffers can reduce sediment delivery from cultivated fields between 84 and 90% and phosphorus by 50% (Copper et al, 1987, and Copper and Gilliam, 1987).

Cooper et al (1987) found that thin riparian strips are effective in trapping sand but less effective for clay. Flood plain swamps or large down stream wetlands were found to provide the best opportunity for clay deposition. Copper concluded that with movement downstream, the buffer zone needs to increase as inputs enter high order streams and the opportunity for deposition decreases while the chances for transport increase.

As discussed above, the effectiveness of buffer strips is primarily the result of the infiltration of dissolved nutrients and reductions in sediment transport capacity caused by decreased water volume and increased resistance to overland flow. Based on this, grass filter and riparian forested buffer strips are best suited for upland areas that do not contain hydric soils. In areas with hydric soil, wetland filters are best suited.

Ecological Impacts

The ecological benefits of stream buffer include the following:

- ! Reductions in sediment loads
- ! Reduced stream velocities
- ! Decreased stream gradients
- ! Maintenance of fish refuge
- ! Sources for coarse organic material for aquatic organisms
- ! Habitat for riparian terrestrial wildlife

Flood Control Impacts

Stream buffer strips can provide significant flood control benefits when combined with protection of the floodplain. Floodplain storage can reduce peak flows and flood elevations. The flood control benefits are proportional to the degree of floodplain that is maintained as storage.

CHAPTER 4

STORMWATER STORAGE AND TREATMENT ALTERNATIVES

Stormwater storage and treatment alternatives include practices that detain stormwater flows, allowing them to be discharged at a controlled rate. The process of temporary storage is called detention. The capacity to hold runoff and release it at a lower rate than incoming flows has made detention a popular practice for flood control and stormwater management. While the stormwater is detained, opportunities can be provided to allow removal of pollutants from the flow stream. Stormwater storage and treatment alternatives include dry detention, extended detention ponds, wet detention ponds, stormwater wetlands, catch basins, and sand filters.

The ponds can be either in-line (Figure 4.1) or off-line (Figure 4.2). The in-line ponds are basically a continuation of the stream channel and the entire flow, including low flow, is typically directed to the pond. The pond is equipped by an overflow that will convey excess flows downstream. Off-line ponds are filled only when the channel capacity is exceeded. Off-line ponds are used for flood control only and have no water quality and only minimal ecological benefits.

Effectiveness of Detention in Controlling Downstream Flooding

The effectiveness of detention in limiting downstream flood impacts is typically measured by change in downstream flood peaks before and after development. The effectiveness of detention in controlling flood impacts is related to the watershed size, event size, location of detention in the watershed, and watershed shape. Depending on the design and watershed characteristics detention storage can produce both positive and negative results.

Watershed Size

Most detention strategies used include controlling post-development peaks to pre-development conditions or less at the outlet of the pond. This is typically done by a process called “peak shaving” where the flows on the storm hydrograph above the pre-developed peak are stored and released at the pre-development rate. Using this guideline most detention is effective in the vicinity of the basin. However, based on several studies, it was concluded that for a given level of detention control, the effectiveness of detention decreases as the distance downstream increases (NIPC, 1989). The reason for this occurrence is the extension, in time, of the peak outflow rates from numerous catchment areas in response to greater post development runoff volume.

Urbanas and Tucker. (1983) in a modeling study of a 20.3 km² (7.85 square mile) watershed in Denver, Colorado, found that local detention designed to limit runoff peaks to the 100-year pre-development condition did not limit downstream flood peaks to pre-development conditions. Whipple et al. (1981) in a modeling study of detention in a hypothetical 32.3 km² (12.5 mi²)



Figure 4.1 Wet stormwater pond near Edinburgh, Scotland. Inlet to the pond is on the left. The pond provides storage and treatment of urban and highway runoff.



Figure 4.2 Off-line retention pond in Osaka, Japan. The river is behind the concrete spillway in the middle left side of the figure. The retention is activated when the flood level in the river exceeds the crest of the spillway. The water is pumped back from the storage after the flood event.

watershed observed that the beneficial effects of detention designed to limit runoff peaks to the pre-development 100-year level diminished rapidly downstream, and disappeared when the drainage area became 32.3 km² (12.5 square miles).

Lau et al. (1987) studied two watersheds in Northeastern Illinois that had proposed limiting the post runoff rate to a 3-year pre-development peak. The study found that for a 12.9 km² (5 square mile) watershed downstream flood peaks were less than pre-development conditions. However, for a 25.9 km² (10 square mile) watershed the post-development peak was greater.

In a study conducted by the Northeastern Illinois Planning Commission (NIPC, 1989), it was concluded that to prevent increases in downstream post-development flood peaks, detention ponds need to be designed to release peak flows at pre-development rates based on a cfs per acre basis. For Northeastern Illinois the recommended release rates are 0.0028 m³/ha (0.04 cfs/acre) for a 2-year storm, and 0.01 m³/ha (0.15 cfs/acre) for a 100-year storm, respectively.

Event Size

Traditionally, detention facilities have been designed to limit the post-development runoff peak for a given interval (e.g., 25-year, 100-year) to pre-development conditions. As a result, basins are designed for single or series of large events. Urbonas and Tucker (1983) and Urbonas and Stahre (1993) concluded that requiring detention to limit the 100-year peak to pre-development conditions has little effect on smaller storm events (e.g., 1-year, 2-year, 10-year) when compared to fully developed conditions without detention. This strategy has little effect on smaller more frequent events that effect channel scour, and bankfull flows.

In an unpublished computer modeling study of Salt Creek by the Lake County Illinois Stormwater Management Commission, it was concluded that by managing flood events for only large storms the frequency of bankfull flows increased. The study evaluated storm events for a 36-year period of rainfall record. The results showed that without detention bankfull flows took place during 110 storms. With the maximum release rate designed for a 3-year storm, the number of bankfull events only dropped to 95. Using a release rate of 0.0028 m³/ha (0.04 cfs/acre) the number of bankfull events dropped to 38 (Personal Communication, Gary Schaefer, Chairman Lake County Stormwater Management Commission, Technical Advisory Committee, December, 1998).

Location of Detention in the Watershed

Location of the detention in a watershed can effect the timing of the peak flows. It has been argued, that providing detention for new development in the lower portion of a watershed may cause increases in flood peaks (NIPC, 1989). By delaying the runoff peak from the lower watershed, it may be released at a point in time, which is coincident with the arrival of the flood peak from the upper watershed, thus worsening the flooding problem.

Lakatos and Kropp (1982) evaluated the location issue for a 7.75 km² (3 square mile) watershed in Pennsylvania. The study found that by delaying the peak discharge from the detention facility by 50 minutes, the peak outflow from the detention facility coincided with the peak from the mainstream

and compounded local runoff impacts. They concluded that for the study watershed, detention would be most effective in the middle of the watershed and least effective in the lower end.

McCuen (1979), in a study of a 18.2 ha (45-acre) development in Montgomery County, Maryland, found that the detention facility could increase the peak 100-year discharge downstream of its junction with another branch for a distance of nearly one mile, when compared to the same development without detention.

The above studies illustrate the point that a watershed wide analysis is needed to understand the positive and negative impacts that detention may have.

Watershed Shape

Watershed shape can greatly effect the time of concentration (or time to peak) of flood flows (NIPC, 1989). In general, in a long narrow watershed the flow per unit area decreases with increasing drainage area. The flow per unit area is reduced much less proceeding downstream in a short wide watershed. The 100-year peak flow in a short, wide watershed is likely to be greater than the 100-year peak in a long narrow watershed because of the shorter time of concentration.

The differences caused by watershed shape can affect detention basin performance (Lau et. al., 1987). The authors reported for a 25.8 km² (10 square mile) short, wide watershed, detention could limit the 100-year post-development flow peak to less than the pre-development peak. For a narrow watershed of the same size and with the same detention requirements, the post-development peak is 3% greater than the pre-development peak. Lau concludes that in a watershed where the flow per unit area is roughly constant with drainage area, local detention facilities can be very effective in reducing regional flood flows. In a watershed where the flow per unit area decreases significantly with drainage area, the same detention facilities are much less effective in reducing regional flood flows. The following analysis of the benefits of the different detention storage alternatives assumes that the designer has conducted a watershed analysis to determine site specific storage and release needs and that the pond that will perform to the desired goals.

Dry Detention Basins

Dry detention basins are storage ponds that are normally empty and designed to hold stormwater temporarily during high peak flows. The outlet of the pond is restricted to regulate the outflows. After the storm event, the pond is allowed to drain down. The size of the outlet is based on the design storms and desired peak outflow. Typically, dry detention basins are designed to control the peak flows only during large storm events, such as 10-, 25- or 100-year storm. Dry detention ponds can be either in-line or off-line. Outlet control is provided by a restricted orifice or pump for in-line ponds and a pump for off-line ponds.

Water Quality Impacts

Dry detention basins provide very limited to no water quality benefits. Suspended solids trapping efficiencies in dry detention ponds are typically in the range of 0 to 20% (Schueler et.al., 1991). The reason for the poor pollution trapping performance has to do with two factors. The first has to do with

the size of the outlet structure. Most dry ponds have outlet structures that restrict flow for only large storms. Studies of urban runoff indicate that 80% of the stormwater pollutants are transported by storms smaller than 3.8 cm (1½ -inch) (Pitt, 1991). Typical dry detention basins pass most small storms with out any detention. The second reason for the ponds poor performance has to do with the location of the outlet. The outlet structures are typically placed at the bottom of the pond and allow the water to completely drain down after the storm. Sediment trapped on the bottom of the pond by one storm can be scoured off the bottom by the next storm.

Ecological Impacts

The ecological benefits of dry detention basins include the following:

- ! Reduced stream velocities during large storms
- ! Decreased stream bed and bank erosion
- ! Decreased stream gradients

Flood Control Impacts

Dry detention basins can provide the following flood control benefits:

- ! Reduced peak flow rates
- ! Reduced downstream flood elevations
- ! Reduced stream velocities

Extended Detention Ponds

Extended detention ponds are modified dry detention basins designed to remove pollutants while still drawing down to a dry area between storms. Extended detention ponds temporarily detain stormwater runoff for up to 24 hours after a storm, much longer than traditional dry detention basins. Such extended detention ponds allow urban pollutants to settle out during storm events, but are designed to prevent resuspension during future storms. Extended detention basins are typically equipped with a riser pipe outlet as compared to the straight outlet pipe in traditional dry detention ponds. A multiple-stage outlet design is usually needed to allow a high discharge rate for large storms, while providing very low outflow rates--possibly by under drains or perforated pipe--for small storms.

In snowbelt zones of North America arbitrarily defined as zones that receive more than 0.6 meters (2 feet) of snow annually, modifications of the extended pond are necessary to secure its functioning during winter. Such ponds should be dry before the winter freeze period begins. Figures 4.3 and 4.4 shows schematics of a standard extended dry pond and a pond modification for snowbelt areas.

Water Quality Impacts

Table 4.1 provides a comparison of the pollution reduction rates for dry detention, extended detention, and wet detention basins. Extended detention basins perform better than dry detention

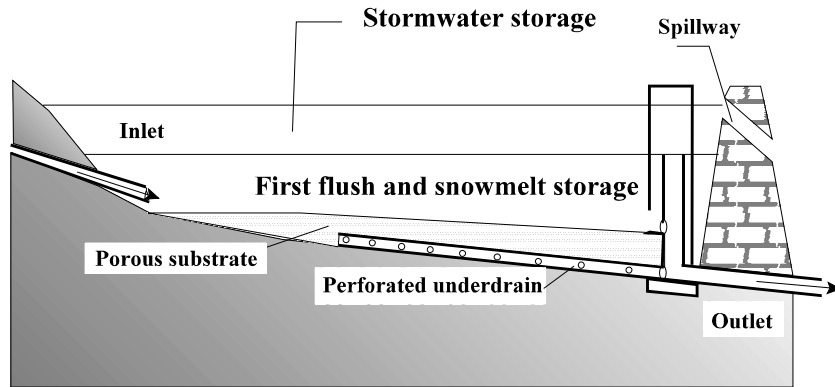


Figure 4-3 Simple extended dry pond. Inlet and outlet should be submerged to reduce freezing problems in snowbelt zones.

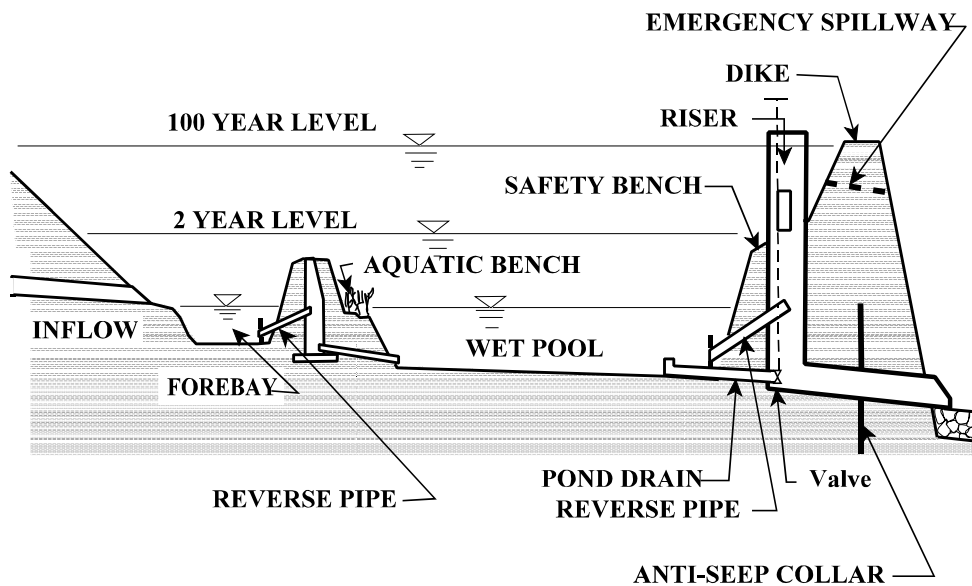


Figure 4.4 Wet pond modified for winter operation. Inlets and outlets should be submerged to reduce freezing. The pond should be drained before winter to provide storage for first flush, chemically induced snowmelt. Adapted from Center for Watershed Protection (1997)

ponds, especially in snow belt areas subjected to extended freeze periods. Extended detention basins are best used where a permanent pool is not safe and pollution control is needed.

Ecological Impacts

The ecological benefits of dry detention basins include the following:

- Reduced stream velocities during large storms
- Decreased stream bed and bank erosion
- Decreased stream gradients
- Reduced pollutant toxicity
- Reduced sediment deposits

TABLE 4.1
Percent pollutant removal capacities of various detention pond designs

Pond Type	Suspended Sediment	Total Phosphorus	Total Nitrogen
Dry detention	0-20		
Extended dry	30-70	10-30	10-60
Wet detention	50-90	30-90	40-80

Source: (Schueler, et.al., 1991)

Flood Control Impacts

The flood control benefits of extended detention basins is similar to those provided by a dry detention pond.

Wet Detention Ponds

Wet detention ponds are impoundments that have a permanent pool of water and also have the capacity to temporarily store stormwater runoff until it is released in a safe manner. Ponds with properly designed permanent pools can trap sediment and prevent it from being scoured off the bottom by future storms. Dry detention ponds have lower pollutant removal efficiencies than wet bottom ponds, as sediment can be scoured off the bottom by incoming flows

Water Quality Impacts

Wet detention ponds are effective at removing particulate-related pollutants. Pollutants removed by wet detention ponds include sediment, nutrients, heavy metals, oxygen demanding compounds,

hydrocarbons, and bacteria. An expanded list of typical pollutant removal efficiencies for wet detention ponds is outlined in Table 4.2.

Pollutant removal in wet detention ponds is primarily due to the settling of particulate pollutants and sediment due to gravity. Three methods for evaluating the performance of wet detention ponds for the removal of suspended solids will be discussed here. The three methods include "overflow theory", a simplified overflow theory method developed by Robert Pitt, and the U.S. EPA Pond Sizing Methodology.

Overflow Theory

The simplest design method for sizing a wet detention basin is based on "overflow theory" where a particle is removed from the water if:

$$OR = \frac{Q}{A_s} < w$$

TABLE 4.2
Pollutant removal efficiencies of
wet detention ponds

Pollutant	Percent Removal
Suspended Solids	85-96%
Oxygen Demanding Compounds	50-70%
Total Phosphorus	40-70%
Dissolved Phosphorus	40-72%
Nitrate Nitrogen	60-80%
Kjeldahl Nitrogen	20-40%
Copper	60-80%
Lead	80-95%
Zinc	40-80%

Source: Walker (1987)

Where:

- OR = overflow rate (m/day)
- Q = inflow in the basin (m³/day)
- A_s = surface area of the basin (m²)
- w = particle settling velocity (m/day)

The particle settling velocity can be estimated from Stoke's Law, or:

$$w = gD^2 / 18\nu (p_s - 1)$$

Where:

- D = particle diameter (m)
- P_s = specific gravity of the particle with respect to water
- g = acceleration of gravity (m/sec)
- ν = kinematic viscosity (m²/sec)

The effectiveness of a wet detention basin to remove particulate pollutants is a direct function of the frequency distribution of the particles in the stormwater. Table 4.3 provides an overview of the percent of pollutant distribution by particle size of street pollutants.

Pitt Method

Robert Pitt (1991) has simplified the pond sizing process using overflow theory by analyzing runoff data from the National Urban Runoff Project (NURP) to size the pond based on land use characteristics of the drainage area and particle size distribution of the runoff. Basically, Pitt has done the above math for the designer. To achieve a 90% removal efficiency of 5 micron and larger particles, Pitt has developed a sizing method that sizes the permanent pool based on a percent of the drainage area and type of land use. Table 4.4 outlines the percent of each land use in a drainage area that is required as a permanent pool. To meet the 90% removal efficiency, the pond must have a minimum depth of 3 feet, and have live storage to retain the runoff from the first 1.25 inches of rainfall. The outlet structure is sized to maintain overflow velocities below the settling velocity of a 5-micron particle.

TABLE 4.3
Percent of street pollutants in various particle-size ranges

Pollutant	Particle Size (um)					
	> 2000	840-2000	240-840	104-240	43-104	< 43
Total solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile solids	11	17.4	12.0	16.1	17.9	25.6
COD	2.4	4.5	13.0	12.4	45.0	22.7
BOD ₅	7.4	21.1	15.7	15.2	17.3	24.3
Phosphorus	0	0.9	6.9	6.4	29.6	56.2
All toxic metals	16.3	17.5	14.9	23.5	-	27.5
TKN	9.9	11.6	20.0	20.2	19.6	18.7
All pesticides	-	27.0	-	-	-	-

PCB's	-	66.0	-	-	-	-
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Source: Sartor, Boyd, and Agardy (1974), Novotny and Olem (1994)

TABLE 4.4
Percent of drainage area required as
wet detention permanent pool

Land Use	Percent of Drainage Area
Freeways	2.8%
Industrial	2.0%
Commercial	1.7%
Institutional	1.7%
Residential	0.8%
Open Space	0.6%

Source: Pitt (1991)

U.S. EPA Pond Sizing Methodology

U.S. EPA (1986) published a methodology for the analysis of detention basins for the control of urban runoff. The procedure is an adoption of probabilistic methodology formulated by DiToro and Small (1979). The method combines probabilistic techniques for the analysis of rainfall and runoff with sedimentation theory for the removal of sediment during dynamic conditions when the pond is filling, and quiescent conditions as the pond drains down. The following equation developed by Fair and Geyer (1954), is used to represent the performance of the pond during dynamic conditions:

$$R_d = 1.0 - [1.0 + 1/n * V_s/Q/A]^{-n}$$

Where:

- R_d = fraction of the initial solids removed under turbulent conditions
- V_s = settling velocity of particles in m/s or ft/s
- Q = peak flow through rate in m³/s or cfs
- A = surface area of the basin m² or sqft
- n = turbulence or short-circuiting constant. Suggested values of n by Fair and Greyer (1954):
 - $n = 1$, poor performance
 - $n = 3$, good performance
 - $n = 5$, very good performance

n = infinity, ideal performance.

During non-storm periods the pond is under quiescent conditions. The following formula represents the performance of the pond during quiescent conditions:

$$R_Q = V_s * A_B$$

Where: R_Q = solids removal rate under quiescent conditions
 V_s = settling velocity of a particle in ft/hr
 A_B = basin surface area, ft².

The duration of storm and non-storm periods is determined from long-term weather statistics from Driscoll, et al. (1989). Percent solids removal is determined from statistical analysis of long term monitoring data.

Ecological Impacts

The ecological benefits of dry detention basins include the following:

- Reduced stream velocities
- Decreased stream bed and bank erosion
- Decreased stream gradients
- Reduced pollutant toxicity
- Reduced sediment deposits

Flood Control Impacts

The flood control benefits of wet detention basins is similar to those provided by a dry detention pond.

Stormwater Wetlands

Stormwater wetlands are shallow pools that create growing conditions suitable for the growth of marsh plants (Figure 4.5 a, b). The wetland are typically designed as several pools in a series with or without a recycle. The wetland provides for shallow stormwater storage and enhanced pollutant removal. Constructed stormwater wetlands are designed to maximize pollutant removal through the processes outlined in Table 4.5.

TABLE 4.5
Biofiltration process of stormwater wetlands

Biofiltration Processes	
Sedimentation	Volatilization
Filtration	Precipitation of colloids

Absorption	Photo-oxidation
Microbial decomposition	Vegetative uptake



Figure 4.5 a Upstream view of a stormwater treatment wetland near Edinburgh, Scotland. The wetland consist of three pools in a series. The upstream pool is a shallow pond, the middle pool has standing water, and the third pool is made of reed basin.



Figure 4.5.b Detail of the second pool and the third pool. Shortcutting in the third pool reduces the treatment efficiency of the wetland

Water Quality Impacts

The effectiveness of natural and constructed wetlands to remove stormwater pollutants is outlined in Table 4.6.

TABLE 4.6
Percent pollutant removal by constructed and natural wetlands

Wetland Type	Suspended Solids	Total Phosphorus	NH₃	Lead	Zinc
Constructed	80	58	44	83	42
Natural	76	5	25	69	62

Source: Strecker et. al. (1992)

As can be seen from Table 4.6, construction wetlands can perform better than natural wetlands for pollutants, such as phosphorus, ammonia, and some heavy metals when properly designed. The performance of a constructed wetland system is dependent on pollutant loading, hydraulic loading, detention time, and pollutant uptake of the system. With constructed wetlands the designer can control the hydraulics of the system to prevent short-circuiting and maximize biological treatment.

Wetland systems are unique in water quality treatment because they allow both aerobic and anaerobic decomposition of wastes to take place in close proximity to each other. This advantage allows wetlands to breakdown wastes that are not treated by other stormwater treatment systems.

Mathematical equations have been developed to calculate average outflow concentrations of total suspended solids (TSS), total phosphorus (TP), and nitrogen given average inflow concentrations, total runoff volume, and area of the wetland (Kadlec and Knight, 1995).

The equation for *total suspended solids* in a free water surface wetland is as follows:

$$C_o = 5.1 + 0.158 C_i$$

$$R^2 = 0.23, N = 1582$$

Where:

- C_o = average annual outflow concentration.
- C_i = average annual inflow concentration.
- R = linear regression coefficient.
- N = number of data points in sample.

There are two equations for the estimation of *total phosphorus* concentrations. One uses an annual hydraulic loading rate and the other uses a daily hydraulic loading rate. The equations give varied results.

The *annual hydraulic loading rate equation for phosphorus* is as follows:

$$\ln(C_o/C_i) = -k/q$$

Where: k = first order areal rate constant, meters/year (m/yr). This has been arrived at empirically and is given as 12 m/yr.
 q = hydraulic loading rate, m/yr.
 (total annual runoff volume)/(wetland area)
 C_i = average annual inflow concentration

The *daily hydraulic loading rate equation for phosphorus* is as follows:

$$C_o = 0.195 q_{avg}^{0.53} C_i^{0.91}$$

Where: $R^2 = 0.77$, $N = 373$
 q_{avg} = daily average hydraulic loading rate, centimeters/day (cm/day).

A background concentration of 0.05 mg/l is added to the outflow concentration.

The equations for nitrogen compounds are as follows:

AMMONIUM NITROGEN $C_o = 0.336 q_{avg}^{0.456} C_i^{0.728}$ (8)

$R^2 = 0.44$, $N = 542$
 Standard Error in $\ln C_o = 1.5$

$0.11 < C_i < 33.3$ mg/l
 $0.04 < C_o < 58.5$ mg/l
 $0.1 < q_{avg} < 58.4$ cm/d

NITRATE NITROGEN $C_o = 0.079 q_{avg}^{0.93} C_i^{0.5}$ (8)

$R^2 = 0.28$, $N = 389$
 Standard Error in $\ln C_o = 1.7$

$0.017 < C_i < 27.4$ mg/l
 $0.50 < C_o < 25.5$ mg/l
 $0.00 < q_{avg} < 21.7$ cm/d

TOTAL NITROGEN $C_o = 0.437 q_{avg}^{0.144} C_i^{0.48}$ (8)

$R^2 = 0.52$, $N = 530$

Standard Error in $\ln C_o = 3.1$

$$0.02 < C_i < 28.6 \text{ mg/l}$$

$$0.25 < C_o < 39.7 \text{ mg/l}$$

$$0.01 < q_{\text{avg}} < 29.1 \text{ cm/d}$$

The daily average hydraulic loading rate can be interpreted two ways. It can be considered to be the total annual loading divided by 365 days, which would only be reasonable for a system which receives steady inflow year round. The daily average hydraulic loading can also be considered the average loading to the wetland on an event basis, which would be more reasonable for a wetland receiving stormwater. This would be considered the event averaged hydraulic loading rate method. The event averaged hydraulic loading rate method more accurately represents the pulse-like inflow of water into a stormwater fed wetland.

Wetland sizing criteria for suspended sediment and phosphorus has been developed based on watershed to wetland ratios, hydraulic loading rates, and pollutant mass loading (Schaefer et al., 1996). In a report by Schaefer, et al. (1996), the authors reviewed the sizing criteria for the removal of total suspended solids and total phosphorus based on studies by the National Urban Runoff Project (NURP), the Northeastern Illinois Planning Commission (NIPC), Metropolitan Washington Council of Governments (MWCOG), Strecker et al., (1992), and USEPA's North American Wetland Data Base (NADB). Table 4.7 outlines the recommended design criteria based on the evaluated studies.

Treatment wetlands have been shown to reduce pathogen levels in surface runoff (Kadlec and Knight, 1995). Fecal coliform reductions in wastewater treatment wetlands have been measured in the range of 86 to 99%. The following equations can be used to estimate the die off rates for fecal bacteria:

Table 4.7
Wetland sizing criteria based on watershed to wetland ratios, hydraulic loading and pollutant mass loading

Source	Watershed to Wetland Ratio	Hydraulic Loading Rate (cm/day)	TP Mass Loading (g/m ² /year)	Percent Total Phosphorus Removal	Percent Total Suspended Solids Removal
NURP	0.024	1.9	4.0	65	90
NIPC	0.042	1.1	-	-	-
Strecker	0.023	2.3	-	64	78
MWCOG	0.021	2.3	-	-	-
NADB	0.043	4.3	4.7	57	71

Source: Schaefer et al. (1996)

Note: all numbers assume an average wetland water depth of 0.31 meters.

$$R = kA(C-C^*)$$

Where: R = death rate, #/day
 k = area-based, first order rate constant, m/d
 A = wetland area, m²
 C = bacterial concentration, #/m³
 C* = background bacterial concentration, #/m³

C* is often in the range of 10 to 500 #/100ml, and k = 75 m/yr for surface flow wetlands, and k = 95 m/yr for sub-surface flow wetlands.

Ecological Impacts

The ecological benefits of stormwater wetlands include the following:

- ! Reduced stream velocities
- ! Decreased stream bed and bank erosion
- ! Decreased stream gradients
- ! Reduced pollutant toxicity by heavy metals and ammonia
- ! Reduced sediment deposits
- ! Increased habitat for wetland wildlife species
- ! Potential for wildlife within the wetland to ingest and bioaccumulate pollutants

Flood Control Impacts

The flood control benefits of stormwater wetlands is similar to those provided by a dry detention pond.

Catch Basins

Catch basins are sumps or chambers installed in storm sewer inlets designed to trap coarse sediment. By trapping coarse sediment, the catch basin prevents trapped solids from clogging the sewer or being washed into receiving waters. To be effective, however, the sumps need to be cleaned periodically.

Water Quality Impacts

Storm sewer inlets with sumps are effective at trapping coarse sediment and large debris such as fast food containers and leaves. Typical catch basins, with a capacity of 0.4 to 1.2 m³ (0.5 to 1.5 cubic yards), have been estimated to retain up to 57% of the coarse solids and 17% of equivalent BOD (MPCA, 1989). A study in Boston, Massachusetts, found catch basins with routine cleaning can reduce solids by 60 to 70%, COD by 10 to 56%, and BOD by 54 to 88% (Aronson, Watson and Pisano, 1983; Field 1986).

In the absence of cleaning, catch basins can actually make water quality conditions worse. It has been reported that once a sump is 40 to 50% full, inflow water can begin to scour sediment and pollutants out of the sump, making the catch basin a source of pollutants (MPCA, 1989). Therefore, catch basins need to be cleaned when they reach 30 to 40% of their storage capacity.

Ecological Impacts

Ecological benefits of catch basin cleaning are limited to reductions in stream pollution inputs.

Flood Control Impacts

Catch basin cleaning provides no flood control benefits.

Sand Filters

Sand filters are a relatively new technique for treating stormwater, whereby the first flush of runoff is diverted into a self-contained bed of sand. The runoff is then strained through the sand to remove pollutants, collected in underground pipes, and returned back to the stream or channel. Sand filters can be designed in several configurations from surface basin filters, underground vaults, and double trench systems.

Water Quality Impacts

Monitoring has shown that by treating the first 1/2 inch of runoff through a sand filter, 85% of the sediment, 40% of phosphorus, and 50 to 70% of both heavy metals and oil and grease can be removed from the runoff (Schueler, et. al 1991).

Sand filters can be sized using a formula derived from Darcy's Law where:

$$A_f = I_a H d_f / k (h + d_f) t_f$$

Where:

A_f = surface area of the sand bed (m^2 , acres or sq. ft.)

I_a = impervious drainage area contributing runoff (m^2 , acres or sq. ft.)

H = runoff depth to be treated (ft.)

d_f = sand bed depth (m or ft.)

k = coefficient of permeability of sand filter (m/hr or ft/hr)

h = average depth of water above sand filter during operation (1/2 max. depth)

t_f = time required for runoff volume to pass through filter (hrs.)

Based on long term observation of existing sand filter basins, the City of Austin, Texas, has recommended a k value of 3.5 feet per day for systems with full sedimentation pretreatment, and 2.0 feet per day for systems with only partial sedimentation pretreatment. (City of Austin, 1988) Full sedimentation pretreatment is defined as complete removal of particles 20 micron and larger. The City of Austin recommends a maximum filter drawdown time (t_f) of 40 hours.

Enhanced sand filters utilize layers of peat, compost, limestone, and/or topsoil, and may also have a grass cover crop. The adsorptive media of enhanced sand filters is expected to improve removal rates. Pollutant removal rates for sand peat filters has been measured at 90% for total phosphorus, 70% for total nitrogen, and 90% for BOD (Schueler, et. al 1991).

Routine maintenance tasks include inspections annually and after large storms, debris removal, and upkeep of the pre-treatment practice, such as grass filter strips. Several design are equipped with back flushing systems used to fluff the bed and maintain permeability of the sand. Periodic maintenance includes the scraping off of the clogged top layer of sand and replenishing the sand material.

Ecological Impacts

Ecological benefits of sand filters are limited to reductions in stream pollution inputs.

Flood Control Impacts

Sand filters provide no flood control benefits.

CHAPTER 5

SUMMARY

Implementation of stormwater management practices reduces the potential impacts of stormwater runoff. The degree of benefits produced by a stormwater practice is dependent on the ratio of watershed area controlled by the practice to the total watershed area. The following tables summarize the potential impacts of stormwater management practices on water quality, ecology, and flooding of streams.

Table 5.1
Water quality impacts of stormwater management practices

STORMWATER MANAGEMENT PRACTICE	IMPACTS ¹							
	REDUCTION IN SUSPENDED SOLIDS	REDUCTION IN PHOSPHORUS	REDUCTION IN NITROGEN COMPOUNDS	REDUCTION IN HEAVY METALS	REDUCTION IN PESTICIDES AND OTHER ORGANICS	REDUCTION OF PATHOGENS	REDUCTION IN OXYGEN DEMANDING COMPOUNDS	POTENTIAL FOR GROUNDWATER CONTAMINATION
Source Controls								
Construction Site Erosion Control	H	H	L	L	L	L	L	L
Street Sweeping	L	L	L	L	L	L	L	L
Fertilizer Management	L	H	H	L	L	L	L	L
Litter Control	H	H	H	L	L	L	H	L
Pet Waste Control	M	M	M	L	L	L	M	L
Volume Reduction Alternatives								
Infiltration Basins	H	H	H	H	H	H	H	H
Infiltration Trenches/Dry Wells	H	H	H	H	H	H	H	H
Porous Pavement	H	H	H	H	H	H	H	H
Grassed Swales	H	H	M/L	H	H	H	H	M/L
Filter Strips	H	H	M	H	H	H	H	M/L
Stream Buffers	H	H	M	H	H	H	H	L
Stormwater Storage and Treatment Alternatives								
Dry Detention Ponds	L	L	L	L	L	L	L	L
Extended Detention Ponds	M	L	M/L	M	L	L	L	M/L
Wet Detention Ponds	H	H	H/M	H	L	M/L	H/M	M/L
Stormwater Wetlands	H	H	H	H	H	H	H	M/L
Catch Basin Cleaning	M	L	L	L	L	L	L	L
Sand Filters	H	M	L	H	-	-	-	-

¹H = High, M = Moderate, L = Low

**Table 5.2
Ecological impacts of stormwater management practices**

STORMWATER MANAGEMENT PRACTICE	IMPACTS ¹							
	REDUCTION IN SUSPENDED SOLIDS	REDUCTION IN PHOSPHORUS	REDUCTION IN NITROGEN COMPOUNDS	REDUCTION IN HEAVY METALS	REDUCTION IN PESTICIDES AND OTHER ORGANICS	REDUCTION OF PATHOGENS	REDUCTION IN OXYGEN DEMANDING COMPOUNDS	POTENTIAL FOR GROUNDWATER CONTAMINATION
Source Controls								
Construction Site Erosion Control	H	H	L	L	L	L	L	L
Street Sweeping	L	L	L	L	L	L	L	L
Fertilizer Management	L	H	H	L	L	L	L	L
Litter Control	H	H	H	L	L	L	H	L
Pet Waste Control	M	M	M	L	L	L	M	L
Volume Reduction Alternatives								
Infiltration Basins	H	H	H	H	H	H	H	H
Infiltration Trenches/Dry Wells	H	H	H	H	H	H	H	H
Porous Pavement	H	H	H	H	H	H	H	H
Grassed Swales	H	H	M/L	H	H	H	H	M/L
Filter Strips	H	H	M	H	H	H	H	M/L
Stream Buffers	H	H	M	H	H	H	H	L
Stormwater Storage and Treatment Alternatives								
Dry Detention Ponds	L	L	L	L	L	L	L	L
Extended Detention Ponds	M	L	M/L	M	L	L	L	M/L
Wet Detention Ponds	H	H	H/M	H	L	M/L	H/M	M/L
Stormwater Wetlands	H	H	H	H	H	H	H	M/L
Catch Basin Cleaning	M	L	L	L	L	L	L	L
Sand Filters	H	M	L	H	-	-	-	-

¹H = High, M = Moderate, L = Low

Table 5.3
Flood control impacts of stormwater management practices

Stormwater Management Practice	Impact ¹		
	Reduced Peak Flows	Reduced Flood Elevations	Reduced Flood Duration
Source Controls			
Construction Site Erosion Control	L	L	L
Street Sweeping	N	N	N
Fertilizer Management	N	N	N
Litter Control	N	N	N
Pet Waste Control	N	N	N
Volume Reduction Alternatives			
Infiltration Basins	H	H	H
Infiltration Trenches/Dry Wells	H	H	H
Porous Pavement	M	M	M
Grassed Swales	M	M	M
Filter Strips	M	M	M
Stream Buffers	H	H	N
Stormwater Storage and Treatment Alternatives			
Dry Detention Ponds	H	H	H
Extended Detention Ponds	H	H	H
Wet Detention Ponds	H	H	H
Stormwater Wetlands	H	H	H
Catch Basin Cleaning	N	N	N
Sand Filters	N	N	N

¹ H = High, M = Moderate, L = Low, N = None

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