URBAN BMP COST AND EFFECTIVENESS

SUMMARY DATA

FOR 6217(g) GUIDANCE

POST-CONSTRUCTION STORMWATER RUNOFF TREATMENT

January 29, 1993

WOODWARD-CLYDE

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1.0 INTRODUCTION

In November 1990, the U.S. Congress passed the Coastal Zone Act Reauthorization and Amendments (CZARA). As part of this reauthorization, Congress created a new, distinct program to address nonpoint source (NPS) pollution of coastal waters (Section 6217). The U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) jointly drafted Proposed Program Guidance for Section 6217. EPA was given the lead responsibility for developing the Management Measures Guidance required under Section 6217(g) of CZARA.

EPA established five Federal/State Work Groups to assist in preparation of the 6217(g) Guidance. Woodward-Clyde has supported the Urban Work Group through the collection and analysis of information on Best Management Practices (BMPs) used to control urban NPS pollution. The results of these efforts includes four books that present cost and effectiveness information on BMPs for:

- Erosion and Sediment Control;
- Post Construction Runoff;
- Onsite Sewage Disposal Systems; and
- Roads, Highways and Bridges.

This report is a summary of the cost and pollutant removal effectiveness information that was obtained from published literature regarding post-construction stormwater runoff treatment. The report also contains appropriate management practices and systems of management practices for the control of NPS pollution after construction and to retrofit existing systems. In accordance with Woodward-Clyde's scope of work, this document only addresses structural management practices.

This document contains information from 41 documents. Also, over 150 documents were reviewed regarding post-construction management practices. The documents were obtained through literature searches and telephone contacts with all states and territories with approved Coastal Zone Management Plans. Cost and effectiveness data from the various management practices presented in the documents were reviewed and analyzed to develop summary information for the various BMPs. Data were omitted from consideration where substandard field technique was used in the collection of the data or if results were influenced by atypical climatological or site characteristics (e.g. unusually heavy rainfall or prolonged drought). Also, only management practices that have been applied in the field were considered. Experimental practices only applied in a research setting were not considered.

This report contains descriptions of the management practices considered, summary cost and effectiveness information, and recommended practices for use in treating post-construction stormwater runoff, and retrofit practices for urbanized areas. The Appendix presents the data analyzed to develop summary cost and effectiveness information.

2.0
EFFECTIVENESS AND COST SUMMARY

This section describes the types of post-construction stormwater runoff management practices considered, where and when these practices can be applied, and the cost and effectiveness of these systems.

Over 150 documents were reviewed and information from 41 documents was used to develop this effectiveness and cost data. It should be noted that the documents obtained and reviewed do not include all of the published literature regarding post-construction stormwater runoff management practices. However, many of the documents obtained were summaries of many other investigations. The influences of soil type, drainage area, climate and many other site specific factors on effectiveness of the practices are discussed. Advantages and disadvantages of the various practices are presented in Table 3-1.

2.1 DESCRIPTION OF POST-CONSTRUCTION STORMWATER RUNOFF TREATMENT

The following is a description of various post-construction stormwater runoff structural management practices. In addition to providing pollutant removal, several practices also can control the post-development peak flow rate which is important for protecting downstream channels from erosion due to increased velocities and runoff volumes.

2.1.1 Infiltration Basins

Infiltration basins are basins that temporarily store runoff while it percolates into the soil through the basins' bottom and sides. Infiltration basins should drain within 72 hours and therefore are generally dry. This is needed to maintain aerobic conditions in order to favor bacteria that aid in pollutant removal and to ensure that the basin is empty for the next storm (Schueler, 1987). Infiltration basins must be designed to trap coarse sediment before it enters the basin proper and clogs the surface soil pores on the basin floor. If there is concentrated flow, a sediment trap could be used to trap the sediment, and if there is sheet flow, a vegetative filter strip could be used.

In-line infiltration basins are typically used for drainage areas from 5 to 50 acres (Schueler, 1987). There must be at least 4 feet of permeable soil (SCS soil group A or B) between the bottom of the basin and bedrock or highwater table. Infiltration basins are not effective when the soil is frozen.

The main factors that influence the removal efficiency are the storage volume, basin surface area and soil percolation rates.

Any runoff that percolates into the ground and reaches surface waters through the groundwater is commonly assumed to have had the pollutants removed by soil processes such as filtration and biological action. Therefore, any runoff and pollutants that percolate into the ground are assumed to be removed. The validity of this assumption depends on the pollutants of concern, their chemical properties and local conditions.

Operation and Maintenance

Routine maintenance requirements include inspecting the basin after every major storm for the first few months after construction and annually thereafter, mowing frequently enough to prevent woody growth, removing litter and debris and revegetating eroded areas. Also, the accumulated sediment should be removed periodically. The infiltration capacity of a soil will decrease over time. If the decrease is due to surface clogging the soil can be deeply tilled or excavated and replaced. Maryland recommends deep tilling every 5 to 10 years (Schueler, 1987). A nonfunctioning infiltration basin can also be converted into a wet pond.

According to an infiltration practice survey completed in Maryland, infiltration basins had a higher failure rate than infiltration trenches or dry wells. Four to six years after construction, only 38% of the basins (as opposed to 53% of the trenches) functioned as designed. The main problems with the basins were inappropriate ponding of water and excessive sediment and debris (Lindsey, 1991).

Infiltration basins that are properly maintained should have a useful life of 25-50 years before the outlet structure needs to be replaced. However, as indicated above the basin's useful life may be shortened due to clogging.

2.1.2 Infiltration Trenches and Dry Wells

Infiltration trenches and dry wells are shallow excavated holes or ditches that have been backfilled with stone to form an underground reservoir. The two practices are similar except that dry wells only control small volumes of runoff, such as the runoff from a rooftop. Infiltration trenches can control several acres of drainage. Infiltration trenches will be discussed in this section, but the information applies to both infiltration trenches and dry wells.

Runoff is temporarily stored in the trench as it percolates into the soil through the trench's bottom and sides. Infiltration trenches should drain within 72 hours to maintain aerobic conditions in order to favor bacteria that aid in pollutant removal and to ensure that the trench is empty for the next storm (Schueler, 1987). Infiltration trench systems must be designed to trap coarse sediment before it enters the trench proper and clogs the soil pores. This may be achieved by using a vegetative filter strip or appropriate upstream inlet design.

Infiltration trenches are typically used for drainage areas less than 5 to 10 acres and may not be economically practical on larger sites. Trenches are sometimes the only economical practice for small sites (Schueler, 1987).

There must be at least 4 feet of permeable soil (SCS soil group A or B) between the bottom of the trench and bedrock or highwater table.

The main factors that influence the removal efficiency are the storage volume, trench surface area, and soil percolation rates.

Any runoff that percolates into the ground and reaches surface waters through the groundwater is assumed to have had the pollutants removed by soil processes such as filtration and biological action. Therefore, any runoff and pollutants that percolate into the ground are assumed to be removed. The validity of this assumption depends on the pollutants of concern, their chemical properties and local conditions.

Operation and Maintenance

Routine maintenance requirements include inspecting the basin after every major storm for the first few months after construction and annually thereafter, mowing the filter strips frequently enough to prevent woody growth and removal of sediment from the pre-treatment device. Despite careful design, construction and maintenance, trenches eventually clog. Studies in Maryland suggest the longevity of trenches may be 10-15 years (Schueler, 1987).

A survey in Maryland of infiltration devices four to six years after construction found only 53% of the infiltration trenches were functioning as designed. The main problems with the trenches were excessive sediment loads and clogging (Lindsey, 1991).

2.1.3 Vegetative Filter Strip

Vegetative filter strips are similar to grass swales, except that they are only effective for overland sheet flow. Runoff must be evenly distributed across the filter strip. If the water concentrates and forms a channel, the filter strip will not perform properly. Level spreading devices are often used to distribute the runoff evenly across the strip. Vegetated filter strips do not effectively treat high-velocity flows and therefore are generally recommended for use in agriculture and low density development and other situations where runoff does not tend to be concentrated. Also, vegetative filter strips are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches.

Vegetative filter strips should have relatively low slopes, adequate length, and be planted with erosion resistant plant species. Vegetative filter strips that treat runoff from roads in areas with freezing winters must contain salt tolerant vegetation. The main factors that influence the removal efficiency are the vegetation, soil infiltration rate, and flow depth and travel time. These are dependent on the contributing drainage area, slope of strip, vegetative cover type and strip length.

Operation and Maintenance

Maintenance requirements for vegetative filter strips are low. The strips should be inspected frequently the first few months after construction to make sure a dense, vigorous vegetation is established and the flow does not concentrate. Strips should be inspected annually thereafter.

Usually if natural vegetative succession is allowed to proceed, little other maintenance is required. Typically, natural succession is the transformation of grass to meadow to second growth forest and it typically enhances pollutant removal. Short strips are typically maintained as lawns and must be mowed 2-3 times a year to suppress weeds and to interrupt natural succession. Excessive use of pesticides, fertilizers, and other chemicals should be avoided. Also accumulated sediment must periodically be removed near the top of the strip (Schueler, 1987).

2.1.4 Grassed Swales

Grassed swales are low gradient, conveyance vegetated channels that are used in place of buried storm drains or curb-and-gutters. To effectively remove pollutants, the swales should have relatively low slope, adequate length, and be planted with erosion resistant vegetation.

The main factors that influence the removal efficiency are the vegetation, soil infiltration rate, flow depth, depth to water table and flow travel time. These are dependent on the contributing drainage area, slope, vegetative cover type and length.

Because swales do not have high pollutant removal rates, they are typically used as part of a stormwater management/management practice system. Swales can replace curb-and-gutter and storm sewer systems in low-density residential and recreational areas. Swales have an advantage over curb-and-gutter and pipes because they can provide pollutant removal, reduce peak flows and have a lower construction cost. However, swales often lead into storm drain inlets to prevent the concentrated flows from gullying and eroding the swale during large storms (Schueler, 1987).

Roadside swales are usually not practical in high density urban areas because each driveway and road intersection must have a culvert. Swales are also not practical on very flat grades, steep slopes, or in wet or poorly drained soils (SWRPC, 1991). Grassed swales that treat runoff from roads in areas with freezing winters must contain salt tolerant vegetation.

Operation and Maintenance

Maintenance requirements are basically the same as normal lawn activities such as mowing, watering, spot reseeding and weed control. However, maintenance can also cause problems such as mowing too close to the ground or excessive application of fertilizers.

The swale should be mowed at least twice each year to stimulate vegetative growth, control weeds, and maintain the capacity of the system. The grass should never be mowed shorter than 3 to 4 inches (Bassler, Undated).

2.1.5 Porous Pavement

Porous pavement, an alternative to conventional pavement, reduces much of the need for drainage conveyance and treatment of the runoff from the paved area. Runoff is diverted through a porous asphalt layer into an underground stone reservoir. Porous pavement has a layer of porous top course covering an additional layer of gravel. A crushed stone-filled groundwater recharge bed is typically installed beneath these top layers. Runoff infiltrates through the porous asphalt layer and into the underground recharge bed. The runoff then exfiltrates out of the recharge bed into the underlaying soils or into a perforated pipe system.

Porous pavement cannot be used where there is high traffic volume or heavy truck traffic. This typically restricts porous pavement use to low volume parking areas. Also, porous pavement is only feasible on sites with gentle slopes.

Porous pavement and recharge beds are usually designed to receive runoff from structures and/or other paved surfaces through a system of pipes or other conveyance system. However, porous pavement should not receive runoff from pervious areas, such as lawns. In fact, porous pavement must be combined with other overall site drainage engineering that carefully directs any sediment or particulate laden runoff away from porous pavement surfaces (Cahill, 1991). Also, there must be at least four feet of permeable soil (SCS soil group A or B) between the bottom of the recharge bed and bedrock or highwater table.

The main factors that influence the removal efficiency are the storage volume, basin surface area, and soil percolation rates.

Any runoff that percolates into the ground and reaches surface waters through the ground water is commonly assumed to have had the pollutants removed by soil processes such as filtration and biological action. Therefore, any runoff and pollutants that percolate into the ground are estimated as being removed. The validity of this assumption depends on the pollutants of concern, their chemical properties and local conditions.

To date, the prime criticism of porous pavement has been its clogging due to sedimentation, especially during the construction phase but also after-construction (Cahill, 1991). If the pavement becomes clogged it is difficult and costly to rehabilitate (Schueler, 1987).

A study conducted in Maryland found that of 13 porous pavement sites that had been constructed four to six years earlier, only 2 facilities were functioning as designed. 77% of the sites had problems with clogging of the facility and 69% had excessive sediment or debris (Lindsey, 1991). Many states no longer promote the use of porous pavement because it tends to clog with fine sediments. (Washington Department of Ecology, 1991).

There may also be problems with the use of porous pavement in cold climates since sand, ash, or deicing salts used for snow removal should never be applied to porous pavement. However, reports have shown that snow and ice melt more quickly on porous pavement. Porous pavement is also more susceptible to freeze-thaw damage than conventional pavement (SWRPC, 1991).

Operation and Maintenance

Routine maintenance of porous pavement includes having the surface vacuum swept followed by high pressure jet hosing at least four times per year to keep the asphalt pores open. In addition, the site should be inspected after every major storm event for the first few months after construction and annually thereafter, and potholes and cracks can be replaced using conventional asphalt if the replaced area does not exceed 10% of the total area. Spot clogging can be treated by drilling holes into the asphalt layer. However, if the facility becomes completely clogged it can only be maintained with complete replacement (Schueler, 1987).

2.1.6 Concrete Grid Pavement

Concrete grid pavement, sometimes referred to as "grasscrete," consists of concrete blocks with regularly interspersed void areas that are filled with pervious materials such as gravel, sand or grass. The blocks are typically place on a sand and gravel base and designed to provide a load-bearing surface that is adequate to support vehicles, while allowing infiltration of surface water into the underlying soil.

As with porous pavement, concrete grid pavement should be used in areas with low traffic volume. Suggested uses are low volume parking spaces, multi-use open space, fire lanes and stream banks/lakeside erosion protection. Concrete grid pavement with grass also require at least five hours of sunlight daily for most grass species to survive. There must also be at least four feet of permeable soil (SCS soil group A or B) between the sand and gravel base and bedrock or high water table.

Concrete grid pavement offers an alternative means in providing load-bearing surfaces without greatly increasing the amount of impervious areas. The main factor that influences the reduction in runoff volume and provides pollutants removal are the amount of open spaces, the slope of the concrete grid pavement; and the underlying soil infiltration rate.

Runoff that percolates into the ground and reaches surface water through the groundwater is commonly assumed to have had pollutants removed by soil processes such as filtration and biological action. Therefore, any runoff and pollutants that percolate into the ground are assumed to be removed. The validity of this assumption depends on the pollutants of concern, their chemical properties and local conditions.

Operation and Maintenance

Like all infiltration practices, concrete grid pavement requires maintenance to prevent clogging of the system. In addition, concrete grid pavement with grass requires additional "normal" grass maintenance, such as mowing, watering and fertilizing. However, extra care should be taken when applying fertilizers and pesticides that may have an adverse effect on concrete products.

With proper maintenance, the life span of concrete grid pavements can be comparable to that of asphalt pavements which is 20 years (Smith, 1981).

2.1.7 Filtration Basins and Sand Filters

Filtration basins and sand filters are basins that are lined with a filter media (such as sand and gravel). Stormwater runoff drains through the filter media and into perforated pipes that are located in the filter media. Detention time is typically 4 to 6 hours (City of Austin, 1990). The runoff typically requires some form of preliminary treatment such as sedimentation. Hence, sediment trapping structures are required for sedimentation to prevent premature clogging of the filter media.

Filtration basins have been used for drainage areas from 3 to 80 acres (City of Austin, 1990). The underdrain pipe system is intended to improve the perculation rate of the soil and/or control the water table elevation. Consequently, filtration basins may be used on sites with impermeable soils (SCS soil group C and D) since the runoff filters through specially placed filter media and pipe system, not native soils. Additionally, a filtration basin's underdrain pipes may lower the water table in its immediate vicinity, and therefore may be used where water table conditions would not allow sufficient infiltration (Livingston, 1988).

The main factors that influence the removal rate are the storage volume, filter media, and detention time.

Operation and Maintenance

Maintenance requirements include inspecting the basin after every major storm for the first few months after construction and annually thereafter, removing litter and debris and revegetating eroded areas. The accumulated sediment should also be periodically removed and the filter media with sediment depositions should be removed and replaced.

2.1.8 Water Quality Inlet - Catch Basin

Catch basins are the simplest form of a water quality inlet. Catch basins are typical single-chambered stormwater inlets except that the bottom of the structure has been lowered to provide 2 to 4 feet between the outlet pipe and structure bottom. This provides a permanent pool of water where sedimentation can occur (City of Austin, 1988).

Operation and Maintenance

To perform properly, catch basins must be cleaned and the accumulated sediment removed. The required frequency of cleaning is dependent on the storage volume and volume of sediment entering the catch basin. A typical cleaning frequency is approximately 4 times a year. However, no acceptable clean-out and disposal techniques currently exist (Schueler et al., 1992).

With proper maintenance, a catch basin should have at least a 50-year life span. However, if the accumulated sediment is not removed it may be resuspended during a storm and actually increase the pollutant load from an individual storm.

2.1.9 Water Quality Inlet - Catch Basin with Sand Filter

Catch basins with sand filters are a variation of "one" chamber catch basins. They consist of two chambers, a sedimentation chamber and filtration chamber that is filled with sand. The runoff first enters the sedimentation chamber that provides effective removal of coarse particles, which helps prevent pre-mature clogging of the filter media. It also provides sheet flow into the filtration chamber that will prevent scouring of filter media (Shaver, 1991). As runoff enters the filtration chamber, additional pollutant removal of finer suspended solids is achieved through filtering.

Catch basins with sand filters are typically used in highly impervious areas with drainage areas less than 5 acres. For larger drainage areas with mixed ground covers filtration basins are used and function on the same principals. Catch basins with sand filters can also be used to retrofit small impervious areas that generate high loads.

Operation and Maintenance

Catch basins with sand filters should be annually inspected and periodically the top layer of sand and deposited sediment should be removed and replaced. The accumulated sediment in the sedimentation chamber should also be removed periodically (Shaver, 1991). However, no acceptable clean-out and disposal techniques for the accumulated sediment currently exist (Schueler et al, 1992).

With proper maintenance and replacement of the sand, the catch basin with sand filter should have at least a 50-year life span.

2.1.10 Water Quality Inlet - Oil/Grit Separator

Oil/grit separators come in many configurations. A common configuration is the 3-chamber oil/grit separator. The first chamber is the sedimentation chamber that allows for sedimentation of coarse material and screening of debris, the second chamber provides separation of oil, grease and gasoline, and third chamber is provided to prevent any possibility of a surcharge pressure from occurring and as a safety relief for the structure if a blockage occurs.

An oil/grit separator should be used in areas receiving high hydrocarbon loadings such as gas stations, loading areas and parking lots. The maximum drainage area to this type of water quality inlet is typically one acre. They are also appropriate for retrofit of small areas that generate high loads of sediment or hydrocarbons such as gas stations and fast food parking lots.

The main factors that influence removal efficiencies are the storage volume for the chambers, design configuration and maintenance frequency.

Operation and Maintenance

The degree and frequency of maintenance will significantly affect the performance of an oil/grit separator. Cleaning the oil/grit separators at regular intervals will prevent the accumulated debris and oil from being discharged from the structure during intense storms. An oil/grit separator should typically be cleaned at least four times a year. However, no acceptable clean-out and disposal techniques currently exist (Schueler et al, 1992).

With proper maintenance, the oil/grit separator should have at least a 50-year life span. However, if the accumulated sediment is not removed it may be resuspended during a storm and actually increase the pollutant load from an individual storm.

2.1.11 Extended Detention Dry Ponds

Extended detention dry ponds temporarily detain a portion of the runoff after a storm and uses an outlet device to regulate outflow at a specified rate, that allows the solids time to settle out. Extended detention dry ponds are typically comprised of two stages: an upper stage that remains dry except for larger storms, and a lower stage that is designed for typical storms. The pond's outlet structure is typically sized for water to be detained at least 12 hours, but fully drain within 72 hours.

Extended detention dry ponds are not typically used for drainage areas less than 10 acres (Schueler, 1987). If the bedrock layer is close to the surface, high excavation costs may make the extended detention dry pond impractical. In addition, if the water table is within 2 feet of the bottom of the pond, there may be problems with standing water.

Extended detention dry ponds cannot typically be used in already developed, heavily urbanized areas because of space constraints. However, they are a practical means of retrofitting dry ponds to obtain water quality benefits.

The main factors that influence the removal efficiencies are the storage volume, detention time, basin shape and degree of maintenance provided.

Operation and Maintenance

Routine maintenance includes mowing, debris/litter removal, inlet and outlet maintenance and inspection. In addition, nuisance control may be necessary for odors and mosquitos problems that are caused by occasional standing water and soggy conditions within the lower stage of an extended detention pond. Non-routine maintenance includes sediment removal. Extended detention dry ponds are estimated to lose approximately 1% of their runoff storage capacity per year due to sediment accumulation. Sediment removal for extended detention dry pond is therefore recommended every 5-10 years with more frequent spot removals around the outlet control device (British Columbia Research Corp., 1991).

Under EPA regulations (40 CFR 261) the material that is cleaned out from a detention pond must be analyzed to determine if it is a hazardous waste. Therefore, a toxicity test should be done for accumulated sediments removed from ponds. If the sediment fails the test, it is subject to the Recource Conservation and Recovery Act (RCRA) and must be disposed of at a RCRA approved facility (Dorman et al, 1989).

With proper maintenance, extended detention dry ponds can have a long useful life. However, concrete pipes used for outlets often need to be replaced after 50 years.

2.1.12 Dry Ponds

These are basins that are almost always dry except for short periods after large storms. They are used to control the peak flow rate, which provides erosion control, but they are not effective for water quality control. However, dry ponds can be retrofitted into extended detention dry ponds to achieve water quality control.

Operation and Maintenance

Dry ponds require similar maintenance and have a similar useful life as extended detention dry ponds.

2.1.13 Wet Ponds

Wet ponds are basins designed to maintain a permanent pool of water and temporarily store stormwater runoff until it is released from the structure at flow rates less than pre-development rates. Unlike extended detention wet ponds the stormwater is not stored for an extended period of time. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed. A fringe wetland can also be established around the perimeter of the pond.

Wet ponds are not typically used for drainage areas less than 10 acres (Schueler, 1987). Pond liners are required if the native soils are permeable (SCS soil group A and B) or if there is fractured bedrock. If the bedrock layer is close to the surface, high excavation costs may make the wet pond impractical. Wet ponds are not typically used in heavily urbanized areas because of space constraints.

The main factors that influence the removal efficiencies are permanent pool volume and pond shape (including inlet and outlet configuration) and degree of maintenance provided.

Operation and Maintenance

Wet ponds require routine maintenance similar to that for extended detention dry ponds. These ponds can be expected to lose approximately 1% of their runoff storage capacity per year due to sediment accumulation. The sediments accumulate out of sight, under the permanent pool. Therefore, wet ponds require less frequent sediment removal when compared to extended detention dry ponds. The recommended sediment clean out cycle is about every 10 to 20 years (British Columbia Research Corp., 1991).

Under EPA regulations (40 CFR 261) the material that is cleaned out from a detention pond must be analyzed to determine if it is a hazardous waste. Therefore, a toxicity test should be done for accumulated sediments removed from ponds. If the sediment fails, the test it is subject to the Recource Conservation and Recovery Act (RCRA) and must be disposed of at a RCRA approved facility (Dorman et al, 1989).

With proper maintenance wet ponds should have a long useful life. However, the concrete pipes used for outlets often need to be replaced after 50 years.

2.1.14 Extended Detention Wet Ponds

Extended detention wet ponds temporarily detain a portion of the runoff after a storm and use an outlet device to regulate outflow at a specified rate, which allows the solids time to settle out. Extended detention wet ponds are designed to maintain a permanent pool of water and temporarily store stormwater runoff for an extended period. The stormwater runoff is typically detained 12 to 72 hours. Enhanced designs include a forebay to trap incoming sediment where it can be easily removed. A fringe wetland can also be established around the perimeter of the pond.

Extended detention wet ponds are not typically used for drainage areas less than 10 acres (Schueler, 1987). Pond liners are required if the pond soils are permeable (SCS soil group A and B) or if there is fractured bedrock. If the bedrock layer is close to the surface, high excavation costs may make the extended detention wet pond not practical. Extended detention wet ponds are typically not used in heavily urbanized areas because of space constraints.

Extended detention wet ponds are typically more effective than the wet ponds, due to the increased settling time provided for the stormwater runoff. The main factors that influence the removal efficiencies are permanent pool volume, pond shape, detention time, and degree of maintenance provided.

Operation and Maintenance

Extended detention wet ponds require similar maintenance and have a similar useful life as wet ponds.

2.1.15 Constructed Stormwater Wetlands

Constructed stormwater wetlands are shallow pools that create growing conditions suitable for the growth of marsh plants. These stormwater wetlands are designed to maximize pollutant removal through wetland uptake, retention and settling. Constructed stormwater wetlands are not usually located within delineated natural wetlands and should be located to have a minimal impact on surrounding areas. In addition, constructed stormwater wetlands differ from artificial wetlands created to comply with mitigation requirements in that they do not replicate all the ecological functions of natural wetlands. (Schueler et al, 1992).

Stormwater wetlands usually fall into one of five basic designs: shallow marsh system, pond/wetland system, extended detention wetland, pocket wetlands, and fringe wetlands.

The main factors that influence the removal efficiency are the size and volume of the wetland system, flow patterns through the wetland area, the wetlands biota, time of year and degree of maintenance.

Operation and Maintenance

Constructed stormwater wetlands have maintenance requirements similar to those for wet ponds. In addition, wetland vegetation should be harvested annually to provide nutrient removal and prevent flushing of dead vegetation from the wetland during the die-down season (British Columbia Research Corp., 1991). The useful life span is indefinite.

2.2 EFFECTIVENESS

Summary effectiveness data for the various BMPs are presented in Section 3 of this document. The following is a discussion of the factors that influence the effectiveness of the various management practices. Effectiveness is defined as the percent pollutant removal that the practice achieves if properly designed, constructed and maintained. Regional and site specific factors such as rainfall amount and duration, vegetation type, soil type and drainage area influence the effectiveness of a practice and are discussed as appropriate. The data analyzed to draw the following effectiveness conclusions are presented in Appendix B.

2.2.1 Infiltration Basins and Infiltration Trenches

Pollutant removal for infiltration devices is achieved by capturing the stormwater runoff and filtering it through the soils under the devices. The infiltration device effectively removes the soluble and fine particle pollutants in the captured water. The coarse grained pollutants should be removed before entering the basin or trench proper to keep it from clogging. The removal mechanisms of the water infiltrating into the soils involve sorption, precipitation, trapping, straining and bacterial degradation and transformation. Actual removal rates in the soil will depend on the solubility and chemistry of the pollutant (Schueler, 1987).

Because there was very little published data on effectiveness of infiltration basins or infiltration trenches, the efficiencies shown as the probable range in Table 3-2 were calculated using a method designed by Woodward-Clyde in 1986. The Woodward-Clyde report "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality" produced a planning level estimate for performance of recharge devices based on percolating area, treatment volume, soil percolation rate and regional rainfall. The report tested the reliability of the results by comparing removal estimates for a range of conditions with those produced by "STORM" and "SWMM" models.

To further test the methodology for this report, results were compared to data in the NURP Final Report (EPA, 1983) for recharge basins in the Great Lake region. The results were similar. In addition, the methodology results were compared to estimated removal rates in Controlling Urban Runoff (Schueler, 1987) and they were consistent. Therefore, the methodology appeared to provide reliable planning level removal rates.

Since there is essentially no difference in the procedure for analyzing infiltration basins and infiltration trenches, they were analyzed together as recharge devices.

For recharge devices, the percent of pollutant removal is the same as the percent of runoff that is captured by the device and infiltrates into the soil. Any runoff that percolates into the ground and reaches surface waters through the groundwater is commonly assumed to have had the pollutants removed by soil processes such as filtration and biological action and hence are ignored by the analysis. Therefore, any runoff and pollutants that percolate into the ground are assumed to be removed.

Removal rates are dependent on an available storage volume. For the probable range of effectiveness shown in Table 3-2, it was assumed that the design volume would equal 90% of the average runoff volume.

Removal rates are also dependent on rainfall patterns that vary regionally. To account for regional differences, the model was run for four different rainfall regions. Regional rainfall data were obtained from "Analysis of Storm Event Characteristics for Selected Rainfall Gages Throughout the United States" (Woodward-Clyde, 1989). The analysis was performed for four CZARA regions including the region with the highest volume and intensity and lowest time between storms (East Gulf), the lowest volume and intensity (Pacific Northwest), the highest time between storms (Pacific South), and approximate average conditions (Mid-Atlantic).

Another important characteristic for removal efficiency is percolation rates. Infiltration devices should only be used at locations with permeable soils (SCS soil type A or B). Since the removal efficiency varies with percolation rate, the efficiency for "A" soils (minimum infiltration rate 2.41 in/hr to 8.27 in/hr) and "B" soils (minimum infiltration rate 0.52 in/hr to 1.02 in/hr) (Schueler, 1987) are presented separately.

The efficiency is also based on the percolating area. Although as discussed above, the storage volume was held constant at 90% of the average runoff volume, the percolating area could vary based on the depth of the pond or trench. The tables assume the minimum depth of a basin is 2 feet and a trench is 3 feet. The maximum depth is 8 feet or the depth that can completely drain within 72 hours.

To determine the maximum removal efficiencies for the two soil groups, the model was run using the maximum percolation rate within the soil group and the maximum percolating area (i.e. minimum depth). The minimum removal rate was based on the minimum percolation rate and minimum percolating area (i.e. maximum depth).

For the infiltration basin the following was used:

	Minimum Removal Rate	Maximum Removal Rate
Soil A	2.4 in/hr perc, 8' height	8.3 in/hr perc, 2' height
Soil B	0.5 in/hr perc, 3' height	1.0 in/hr perc, 2' height

Since the infiltration trench is filed with stone, the available storage space typically equals 40% the excavation volume (Schueler, 1987). Therefore, the effective height of an 8-foot trench is 8 feet x 40% = 3.2 feet. It is the available storage volume and effective height which are important when determining the removal efficiency.

Therefore, for the infiltration trench the following was used:

	Minimum Removal Rate	Maximum Removal Rate
Soil A	2.4 in/hr perc, 3.2' height	8.3 in/hr perc, 1.2' height
Soil B	0.5 in/hr perc, 3' height	1.0 in/hr perc, 1.2' height

The range of removal rates was estimated based on the runs for the four regions. It was determined that the regional differences in removal rates were not large enough to justify reporting removal rates regionally (see Appendix B for model results).

2.2.2 Vegetative Filter Strip

Properly designed and functioning vegetative filter strips effectively remove particulates such as sediment, organic matter and many trace metals by the filtering action of the grass and deposition. Removal of soluble pollutants is achieved by infiltration into the soil and is probably not very effective since only a small portion of the runoff passing through a vegetative filter strip usually infiltrates. Forested filter strips appear to be more effective than grassed strips, but a longer length is required for optimal removal rates (Schueler, 1987).

Several sources of information on urban vegetative filter strips (VFSs) and several on agriculture VFSs were obtained. Most of the reports gave removal rates for a specific VFS slope and length. To provide probable removal rates that could be used at the planning level, Table 3-2 was developed from the chart prepared by Dorman et al, 1989 for the Federal Highway Administration (FWHA).

The FHWA report (Dorman et al, 1989) is based on research and monitoring done for highways. However, the removal mechanisms and rates of VFSs should be the same on highway sites as on urban sites and therefore are applicable. The depth of flow in the VFS was assumed to be less than 4 inches to estimate removal rates that could be provided from properly designed urban VFSs using the chart prepared by Dorman et al, 1989. This would be appropriate for almost all VFSs since they are designed for sheet flow and not concentrated flow. The travel time was assumed to be greater than 5 minutes, which also should be appropriate for correctly designed VFSs, since the strip should have a low slope and adequate length.

The total suspended solids (TSS) removal efficiency range was read from the chart. In addition, the research indicated that the lead removal rate is approximately 90% of the TSS removal rate and zinc removal is approximately 60% of TSS.

These removal efficiency ranges are similar to reported ranges in other references. The report indicated that total phosphorous (TP) and total nitrogen (TN) removal rates could not be easily related to depth of flow and travel time. Therefore, TP and TN removal rates for Table 3-2 were taken as the range from the other references, excluding turf strips.

It must be noted that the cited removal rates are based on ideal conditions - evenly distributed sheet flow and a dense, vigorous vegetative cover. However, if the water concentrates, removal rates can be significantly less and if eroded gullies form the vegetative filter strip could actually be a source of sediment.

2.2.3 Grassed Swales

Properly designed and functioning grassed swales provide some pollutant removal through filtering by vegetation of particulate pollutants, biological update of nutrients and infiltration of runoff. However, because the flow is concentrated the removal rates are low (SWRPC, 1991). Swales are not generally effective in removing soluble pollutants. Also, in some cases trace metals have leached from swale culverts and nutrients have leached from fertilizers. Consequently, these pollutant concentrations have actually increased (Schueler, 1987).

Several sources of information on grassed swales were reviewed. However the reported percent removal for TSS varied from 0 to >99%. These differences are most likely due to differences in the swale length and slope. Since swales in urban areas are typically short in length, the high removal rates are probably not possible. However, if properly designed, a swale with a low slope should achieve some pollutant removal.

2.2.4 Porous Pavement

Two porous pavement studies were cited in the literature. They both obtained relatively high pollutant removal rates. However, as stated previously, a Maryland study found that of 13 porous pavement sites that had been constructed 4 to 6 years earlier, only 2 facilities were functioning as designed. Several of the sites evaluated failed due to clogging of the surface from sediment during and following construction, as a result of sediment-laden runoff being conveyed to the porous pavement surface.

2.2.5 Concrete Grid Pavement

The information on the removal efficiencies of concrete grid pavements is obtained from laboratory studies by Day, et.al., 1981 and monitoring studies for a parking lot in downtown Dayton, Ohio by Smith, et.al., 1981.

The laboratory studies by Day provide information on the runoff volume and pollutant load reductions associated with concrete grid pavements. The monitoring studies by Smith provide the removal efficiencies of concrete grid pavements as the reductions in pollutant concentration and mass in water that has percolated through the concrete grid pavements. For the purpose of this report, the pollutant removal efficiencies of the concrete grid pavement presented from both studies shall be interpreted as the reduction in runoff volume. Any runoff that percolates into the ground and reaches surface waters through the groundwater is assumed to have had the pollutants removed by soil processes such as filtration and biological action. Therefore, the removal efficiencies of pollutant is assumed to be the reduction in runoff.

Concrete grid pavements are basically a form of infiltration measures. Therefore, as a reference, their pollutant removal efficiencies should be similar to that of porous pavements.

2.2.6 Filtration Basin

Removal efficiencies for filtration basins were obtained primarily from two sources: laboratory studies done in 1981 (Wanielista et al, 1981 cited in City of Austin, 1988) and monitoring studies done on several filtration basins in Austin, Texas, 1990.

The Austin report contained the monitoring results for several basins and estimated expected removal rates for several possible designs based on the monitoring results. Three of the designs were chosen as appropriate for this category and are off-line sedimentation/filtration basin, on-line sand/sod filtration basin, and on-line sand basin. The expected removal rates are consistent with the monitoring study results and laboratory study. Therefore, the range of probable removal rates given in Table 3-2 are the same as the expected removal rates presented in the Austin Report, with two exceptions. The highest expected removal rate for TSS is 100%. However, during large storms some of the runoff will not be treated, and 100% removal does not seem realistic. Consequently, the high range of TSS removal was reduced to 90% for Table 3-2. In addition, the expected removal rates do not include COD, so the COD removal rates reported from the monitoring study were used.

2.2.7 Water Quality Inlet - Catch Basin

There are very little data available regarding the effectiveness of water quality inlets. The configurations of outlet pipe and the permanent pool for sedimentation allow the catch basins to function as small sediment basins with short detention time and high degree of turbulence. Catch basins appear to trap only coarse-grained sediments.

2.2.8 Water Quality Inlet - Catch Basin with Sand Filter

The effectiveness of catch basins with sand filter are estimated to be similar to filtration basins. However, there are no available monitoring studies for catch basins with sand filters. The effectiveness of the sediment chamber for removal of the different size particles depends on the particle's setting velocity and the chamber's length and depth. The effectiveness of the filtration media depends on the depth of the filter media.

2.2.9 Water Quality Inlet - Oil/Grit Separator

The pollutant removal of an oil/grit separator has not been widely tested in the field. Removal efficiencies for oil/grit separators were obtained from two references. These references indicated that oil/grit separators have marginal TSS removal efficiency, i.e., less than 25%. These removal efficiencies are general estimates that inferred from studies on similar structures such as catch basins. There were no specific oil and grease removal efficiencies provided for oil/grit separators but oil and grease removal can be improved with the aid of adsorbent (Silverman et al., 1988). One such application is to place the adsorbent in a removable fine mesh bag; replacement of the adsorbent could be accomplished by replacing the exhausted bag with one containing fresh adsorbent.

2.2.10 Extended Detention Dry Pond

Seven sets of information on removal efficiencies for extended detention dry ponds were available in Schueler et al, 1992. The removal efficiency of TSS fell into two distinct ranges. Four ponds' removal efficiencies were from 3% to 30%, and three ponds' removal efficiencies were from 70% to 87%. All of the ponds in the lower range had short detention times (under 10 hours). Settling column experiments have shown that most settling of suspended pollutants occurs within the first 12 hours (OWML, 1983 cited in Schueler, 1987). Therefore, extended detention ponds should provide a minimum of 12 hours detention. Using this criteria, the 4 ponds with the low detention times were determined to have insufficient detention time and therefore discounted for determining the probable range of effectiveness for properly designed and maintained extended detention dry ponds. The removal efficiencies for the remaining three ponds were used to determine the probable range of removal for extended detention dry ponds.

2.2.11 Wet Pond

Twenty-four sets of information on wet ponds' removal efficiencies were available in Schueler et al, 1992. Current literature indicates that removal efficiency should increase with increased treatment volume. However, plotting the treatment volume (inch per drainage acre) versus removal efficiency did not show this for the ponds. This is probably due to many site specific variables. Of the twenty-four, three had reported TSS removal efficiency of <32% while twenty-one had TSS removal efficiency >54%. The three ponds with substantially lower reported removal rates may be due to difference in calculation methods (pond #25) and the storage volume being considerably less (ponds #9 and #10). Since these three ponds' removal efficiencies were substantially different for most pollutants, they were discounted for determining the probable removal rate of a properly designed and maintained wet pond. The probable removal rates given in Table 3-2 show the range of the remaining efficiencies.

2.2.12 Extended Detention Wet Pond

Data on removal efficiencies for three extended detention wet ponds were available in Schueler, 1992. Table 3-2 shows the range of efficiencies for TSS and TP from the raw data. As expected, the TSS and TP removal efficiency for the extended wet pond were higher than for the wet pond. However, there was not sufficient information on the remaining pollutants to come to a similar conclusion. However, the extended detention wet pond probably provides higher removal rates for all pollutants due to the increased detention time (which allows additional settling) and the additional aquatic fringe (which provides increased biological uptake).

2.2.13 Constructed Stormwater Wetlands

The pollutant removal performance of nearly twenty stormwater wetland systems were reported in Woodward-Clyde, 1991. The probable range of removal effectiveness in Table 3-2 is for the designs with a minimum area of wetland equal to 1% of the drainage area. Although the stormwater wetland systems monitored have differed greatly in their design and treatment volume, most have shown moderate to excellent pollutant removal capability under a range of environmental conditions (Schueler et al, 1992).

Stormwater wetlands pollutant removal capability is comparable to that of wet ponds. Sediment removal may be greater in well designed stormwater wetlands, but phosphorous removal is more variable.

2.3 COST

The cost of the management practices varies greatly and is dependent upon many factors such as availability and proximity of materials, time of year and labor rates. The costs presented in this document are a summary of costs found in published documents. These costs are presented to give planners an idea of the cost of a practice relative to another and are not recommended for use in estimating or bidding construction contracts. Local suppliers and contractors could be contacted for this purpose. Cost data were generally influenced more by proximity to major urban centers rather than regionally. Consequently, regional variation of cost could not be supported by the data obtained. It may be more effective to consider the cost ranges presented as "national" averages and to adjust the cost on a regional basis using published regional cost variation indexes (e.g., the regional cost index published by the Engineering News Record).

Quantitative cost data are discussed in Section 3.0 and presented in Table 3-3. Table 3-3 summarizes the total annual cost, including the annualized construction cost. To annualize this cost an interest rate of 5% was assumed. The cost data used to develop these cost summaries are presented in the Appendix.

The costs presented are only construction costs. It does not include the cost of such items as land, engineering, and review fees.

The cost of the management practices are dependant on the treatment volume. Due to economy of scale, as the treatment volume increases, the cost per cubic foot of water treated decreases. Ponds tend to be the most economical practice for larger drainage areas. Infiltration trenches and water quality inlets are typically only cost effective for relatively small drainage areas. Vegetative controls are relatively inexpensive. In fact, grassed swales are less expensive to construct than curb-and-gutter.

The following is a discussion of the factors that influence the costs that can be expected in implementing various management practices.

2.3.1 Infiltration Basins

The cost of infiltration basins is directly related to the storage volume. Due to economy of scale, as storage volume increases, cost per unit volume decreases. Infiltration basins are typically cheaper per unit volume than extended detention dry ponds due to decreased cost of the outlet structure. Infiltration basins are also cheaper on a per volume basis than infiltration trenches.

2.3.2 Infiltration Trenches

The cost of infiltration trenches is directly related to storage volume. As the storage volume increases, cost per unit volume decreases. Schueler, 1987 indicates that infiltration trenches may not be economically practical on sites larger than 5 to 10 acres.

2.3.3 Vegetative Filter Strip

The cost of a VFS is dependent on the type of vegetation used in the strip. If the natural vegetation is maintained, the cost is minimal.

Generally an area that will serve as a VFS should not be cleared and graded, since it is more effective if the natural vegetation is maintained. A VFS should only be seeded or sodded if the area is disturbed for the associated development, otherwise it should remain undisturbed. Therefore the cost of VFS is assumed only to include the cost for sod or seed and any cost for clearing and grading is a cost associated with site development and not installation of the practice.

2.3.4 Grassed Swale

The cost of a grassed swale will vary depending upon the geometry of the swale (height and width) and method of establishing the vegetation (seed or sod). The construction cost of grassed swales are typically less than curb-and-gutter. However, the maintenance cost of swales is generally higher than curb-and-gutter.

2.3.5 Porous Pavement

The cost of porous pavement should be measured as the incremental cost, or the cost beyond that required for conventional asphalt pavement. However, to determine the full value of porous pavement one should also consider the savings from reducing land consumption and eliminating storm systems, e.g. curbs, inlets and pipes (Cahill, 1991). Also, one must consider the additional cost of directing pervious area runoff around porous pavement.

2.3.6 Concrete Grid Pavement

The cost per square foot of concrete grid pavements will vary depending on the types and specifications of concrete grid pavements and the existing underlying soil conditions. Currently, there are no ASTM standards specification governing properties of concrete grid pavement units. However, the National Concrete Masonry Association (NCMA) has published an industry standard specification for concrete grid pavers designated as A-15-82.

In addition to the initial installation cost, there will be maintenance costs such as grass mowing, fertilizing and reseeding. The cost of concrete grid pavement is presented as the incremental cost, i.e., cost beyond that required of conventional asphalt pavement. The incremental cost of maintenance for concrete pavement shows a net decrease from that of asphalt pavement. When comparing the maintenance cost between concrete grid and asphalt pavements, concrete grid pavement does not require the minimum one overlay that is assumed necessary during the 20 year lifespan of asphalt pavement.

The concrete grid pavement installed in place and annual maintenance cost presented in Table 3-3 is based on information provided by NCMA.

2.3.7 Filtration Basin

Data regarding the costs of filtration basins were obtained from engineers' estimates done in Austin, Texas for various sized basins (Tull, 1990). These reported costs per cubic foot of storage are higher than reported costs for infiltration devises, dry extended detention ponds or wet ponds. No information was available regarding the maintenance costs of filtration basins. However, because filtration basins function similar to infiltration basins, the annual operation and maintenance cost was assumed to be the same percent of capital cost as infiltration basins.

2.3.8 Water Quality Inlet - Catch Basin

In general, the cost of catch basins will be similar to those for standard precast inlets. The annual maintenance cost of cleaning catch basins will depend on the number of times per year they are cleaned and the method used. Cleaning catch basins manually by hand or with clamshell buckets costs approximately twice as much as cleaning with a vacuum attachment to a sweeper (SWRPC, 1991).

2.3.9 Water Quality Inlet - Catch Basin with Sand Filter

The cost of a catch basin with sand filter will depend on the size of the sedimentation and filtration chambers, which depends on the drainage area. No information was available regarding the maintenance cost of catch basins with sand filters. However, information was available on the maintenance cost of oil/grit separators. It was estimated that the maintenance cost of catch basins with sand filters would be higher than oil/grit separators since the sand filter must be periodically replaced. Please note that although maintenance costs of catch basins were available, they could not be used since they are reported in a different unit than catch basins with sand filters (each verse drainage acre).

2.3.10 Water Quality Inlet - Oil/Grit Separator

The cost of the oil/grit separator will depend on the storage volume of the chambers, which in turn depends on the drainage area and the configuration of the design components.

The annual cost of maintenance of oil/grit separators will depend on the number of times per year they are cleaned and the method used. The maintenance costs were assumed to be the same as cleaning catch basins.

2.3.11 Extended Detention Dry Pond

The cost of ponds is directly related to the storage volume. In addition, if the bedrock layer is close to the surface, high excavation costs may make extended detention dry ponds impractical. The cost of dry ponds were obtained from four sources. In addition, Chart 4, in Appendix C, shows the economy of scale for extended detention dry ponds.

2.3.12 Wet Pond

The cost of ponds is directly related to the storage volume. In addition, if the bedrock layer is close to the surface the cost may increase exponentially.

The costs of wet ponds were obtained from four sources. The wide cost differences shown on the wet pond cost chart is probably due to the less expensive ponds being constructed in natural low lying areas where little or no excavation was required. However, these low lying areas are often wetlands, and due to present-day strict wetlands laws, these low costs may not be realistic in 1991.

2.3.13 Extended Detention Wet Pond

The cost of an extended detention wet pond should be similar to the wet pond. The main cost difference would be the outlet structure for the extended detention pond would need to be designed to temporarily store the stormwater runoff.

There was no information available for extended detention wet pond costs, but in some cases the cost difference between wet ponds and extended detention wet ponds will be minimal. Therefore, it was assumed that wet ponds and extended detention wet ponds have the same cost.

2.3.14 Constructed Stormwater Wetlands

Construction costs for stormwater wetlands have not been systematically analyzed, but are expected to be marginally higher than wet ponds due to the more complex grading and wetland planting costs. Maintenance costs may average between three and five percent of construction costs annually (Schueler et al, 1992).

This section presents summary effectiveness and cost tables (Table 3-1, 3-2, and 3-3) for the various management practices discussed in this document. These summary tables are based on the detailed cost and effectiveness data presented in the Appendix. It should be noted that only practices that had enough quantitative data on which to base conclusions are presented in the tables.

Table 3-1 summarizes the advantages and disadvantages of the various management practices.

Table 3-2 summarizes the effectiveness of the various management practices. Effectiveness was defined as the percent pollutant removal that the practice achieves if properly designed, constructed and maintained. There are many pollutants found in urban runoff and the effectiveness can be measured for each of the pollutants. Researchers have not come to a consensus as to what pollutants are the best to use for measuring effectiveness. However, the pollutants that appear to be of most concern are Total Suspend Solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN), Chemical Oxygen Demand (COD), Lead (Pb), and Zinc (Zn). Therefore, management practices' effectiveness for these pollutants are tabulated in Table 3-2.

Pollutant removal is achieved through complex chemical, biological, and physical processes. Due to the complexity of the processes and their dependence on a large variety of parameters, researchers have not come to a consensus as to the effectiveness of the practices. Therefore, Table 3-2 presents the effectiveness information and includes the average and range observed in the reviewed literature, the probable range expected from a properly designed and maintained practice (based on the literature and issues discussed in Section 2.2), and the number of references considered in developing these data.

During the literature search for this project, it was apparent that there have been a limited number of monitoring studies completed regarding the effectiveness of these management practices. The results of the studies that were available are summarized in Table 3-1. However, performance monitoring studies are difficult to compare due to the differences in the studies. The following variables are involved in BMP performance monitoring (Schueler, 1992):

- Number of storms monitored;
- Type and size of storm monitored;

- BMP design variations;
- Monitoring technique used;
- Pollutant removal calculation technique used;
- Seasons monitored; and
- Characteristics of contributing watershed.

It is also difficult to quantify the pollutant removal capabilities of a BMP because the performance varies from storm to storm. The pollutant removal capabilities of a BMP will also vary during the BMP's lifetime (Schueler, 1992).

Table 3-3 presents construction and annual maintenance cost information. The cost information in this table is annualized so that comparisons can be made from one practice to another. The annualized cost was determined by assuming an interest rate of 5%. Some practices have limited useful lives. However, other practices will continue to provide water quality benefits indefinitely if properly maintained. To annualize the capital costs of those practices, they were assumed to have an useful life of 50 years. These costs are presented to give planners an idea of the cost of practice relative to another and are not recommended for use in estimating or bidding construction contracts.

TABLE 3-1. ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1]

MANAGEMENT PRACTICE	ADVANTAGE	DISADVANTAGE
Infiltration Basin	• Provides groundwater recharge • Can serve large developments • High removal capability for particulate pollutants and moderate removal for soluble pollutants • When basin works, it can replicate predevelopment hydrology more closely than other BMP options • Basins provide more habitat value than other infiltration systems	• Possible risk of contaminating groundwater • Only feasible where soils permeable and have sufficient depth to rock and water table • Fairly high failure rate • If not adequately maintained can be eyesore, breed mosquitos and create undesirable odors • Regular maintenance activities cannot prevent rapid clogging of infiltration basins
Infiltration Trench	• Provides groundwater recharge • Can serve small drainage areas • Can fit into medians, perimeters and other unutilized areas of a development site • Helps replicate predevelopment hydrology, increases dry weather baselfow, and reduces bankfull flooding frequency	• Possible risk of contaminating groundwater • Only feasible where soils permeable and have sufficient depth to rock and water table • Since not as visible as other BMPs, less likely to be maintained by residents • Requires significant maintenance
Vegetative Filter Strip (VFS)	• Low maintenance requirements • Can be used as part of the runoff conveyance system to provide pre-treatment • Can effectively reduce particulate pollutant levels in areas where runoff velocity is low to moderate • Promotes groundwater recharge, urban wildlife habitat, and stream bank stabilization • Economical	• Often concentrates water, which significantly reduces effectiveness • Ability to remove soluble pollutants highly variable • Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated • Requires periodic repair, regrading, and sediment removal to prevent channelization
Grassed Swale	• Requires minimal land area • Can be used as part of the runoff conveyance system to provide pretreatment • Can provide sufficient runoff control to replace curb and gutter in single-family residential subdivisions and on highway medians • Economical • Low slope swales can create wetland habitat	• Low pollutant removal rates • Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients • Requires more land than curb and gutter • Can impact on groudwater quality in certain situations

TABLE 3-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (continued)

MANAGEMENT PRACTICE	ADVANTAGE	DISADVANTAGE
Porous Pavement	• Provides groundwater recharge • Provides water quality control without additional consumption of land • Can provide peak flow control • High removal rates for sediment, nutrients, organic matter, and trace metals • When operating properly can replicate predevelopment hydrology • Eliminates the need for stormwater drainage, conveyance, and treatment systems off-site	• Requires regular maintenance • Possible risk of contaminating groundwater • Only feasible where soil is permeable, there is sufficient depth to rock and water table, and there are gentle slopes • Not suitable for areas with high traffic volume • Need extensive feasibility tests, inspections, and very high level of construction workmanship (Schueler, 1987) • High failure rate due to clogging • Not suitable to serve large off-site pervious areas
Concrete Grid Pavement	• Can provide peak flow control • Provides groundwater recharge • Provides water quality control without additional consumption of land	• Requires regular maintenance • Not suitable for area with high traffic volume • Possible risk of contaminating groundwater • Only feasible where soil is permeable, there is sufficient depth to rock and water table, and there are gentle slopes
Sand Filter/Filtration Basin	• Ability to accommodate medium size development (3-80 acres) • Flexibility to provide or not provide groundwater recharge • Can provide peak volume control • Can be used in areas where groundater quality concerns precludes the use of infiltration	• Requires pretreatment of stormwater through sedimentation to prevent filter media from premature clogging • Larger designs without grass covers may not be attractive in residential areas • Do not provide significant stormwater detention for downstreams areas
Water Quality Inlets	• Provides high degree of removal efficiencies for larger particles and debris as pre-treatment • Requires minimal land area • Flexibility to retrofit existing small drainage areas and applicable to most urban areas	• Not feasible for drainage area greater than 1 acre • Marginal removal of small particles, heavy metals and organic pollutants • Not effective as water quality control for intense storms • Minimal nutrient removal
Water Quality Inlet with Sand Filter	• Provides high removal efficiencies on particulates • Requires minimal land area • Flexibility to retrofit existing small drainage areas • Higher removal of nutrient as compared to catch basins and oil/grit separator	• Not feasible for drainage area greater than 5 acres • Only feasible for areas that are stabilized and highly impervious • Not effective as water quality control for intense storms

TABLE 3-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (continued)

MANAGEMENT PRACTICE	ADVANTAGE	DISADVANTAGE
Oil/Grit Separator	• Captures coarse-grained sediments and some hydrocarbons • Requires minimal land area • Flexibility to retrofit existing small drainage areas and applicable to most urban areas • Shows some capacity to trap trash, debris, and other floatables • Can be adapted to all regions of the country	• Not feasible for drainage area greater than 1 acre • Minimal nutrient and organic matter removal • Not effective as water quality control for intense storms • Concern exists over the pollutant toxicity of tapped residuals • Require high maintenance • Pulse hydrocarbon loads may result from resuspension during large storms
Extended Detention Dry Pond	• Can provide peak flow control • Possible to provide good particulates removal • Can serve large development • Requires less capital cost and land area when compared to wet pond • Does not generally release warm or anoxic water downstream • Provides excellent protection for downstream channel erosion • Can create valuable wetland and meadow habitat when properly landscaped	• Removal rates for soluble pollutants are quite low • Not economical for drainage areas less than 10 acres • If not adequately maintained can be eyesore, breed mosquitos and create undesirable odors
Wet Pond	• Can provide peak flow control • Can serve large developments, most cost effective for larger more intensively developed sites • Enhance aesthetic and provide recreational benefits • Little groundwater discharge • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Provides moderate to high removal of both particulate and soluble urban stormwater pollutants • Creates wildlife habitat • Very useful in both low and high visibility commercial and residential development	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained can be eyesore, breed mosquitos and create undesirable odors • Requires considerable space which limits their use in densely urbanized areas with expensive land and property values • Not suitable for hydrologic soil group "A" and "B" (*SCS* classification) • With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life
Extended Detention Wet Pond	• Can provide peak flow control • Can serve large developments, most cost effective for larger more intensively developed sites • Enhance aesthetic and provide recreational benefits • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Provide better nutrient removal when compared to wet pond • Creates wildlife habitat	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained can be eyesore, breed mosquitos and create undesirable odors • Requires considerable space which limits their use in densely urbanized areas with expensive land and property values • Not suitable for hydrologic soil group "A" and "B" (SCS classification) • With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life

TABLE 3-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (continued)

MANAGEMENT PRACTICE	ADVANTAGE	DISADVANTAGE
Constructed Stormwater Wetland	• Can serve large developments, most cost effective for larger more intensively developed sites • Provides peak flow control • Enhance aesthetic and provide recreational benefits • The marsh fringe also protects shoreline from erosion • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Has high pollutant removal capability • Creates wildlife habitat	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained can be eyesore, breed mosquitos and create undesirable odors • Requires considerable space which limits their use in densely urbanized areas with expensive land and property values • With possible thermal discharge and oxygen depletion may severely impact downstream aquatic life • May contribute to nutrient loadings during die-down periods of vegetations

[1]Several items taken from Schucher et al, 1992.

TABLE 3-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
INFILTRATION BASIN:	Ave:	75	65	60	65	65	65	• Soil percolation rates • Basin surface area • Storage Volume	Schueler, 1987; EPA, 1983; Woodward-Clyde, 1986
	Reported Range:	45-100	45-100	45-100	45-100	45-100	45-100		
	Probable Range (1):								
	SCS Soil Group A	60-100	60-100	60-100	60-100	60-100	60-100		
	SCS Soil Group B	50-80	50-80	50-80	50-80	50-80	50-80		
	No. Values Considered:	7	7	7	4	4	4		
INFILTRATION TRENCH:	Ave:	75	60	55	65	65	65	• Soil percolation rates • Trench surface area • Storage Volume	Schueler, 1987; EPA, 1983; Woodward-Clyde, 1986; Kuo, et al, 1988; Lugbill, 1990
	Reported Range:	45-100	40-100	(-10)-100	45-100	45-100	45-100		
	Probable Range (2):								
	SCS Soil Group A	60-100	60-100	60-100	60-100	60-100	60-100		
	SCS Soil Group B	50-90	50-90	50-90	50-90	50-90	50-90		
	No. Values Considered:	9	9	9	4	4	4		
VEGETATIVE FILTER STRIP	Ave:	65	40	40	40	45	60	• Runoff volume • Slope • Soil infiltration rates • Vegetative cover • Buffer length	IEP, 1991; Casman, 1990; Glick, et al, 1991; VA Dept. of Cons., 1987; Minnesota PCA, 1989; Schuler, 1987; Hartigan, et al, 1989
	Reported Range:	20-80	0-95	0-70	0-80	20-90*	30-90**		
	Probable Range (3):	40-90	30-80	20-60	--	30-80	20-50		
	No. Values Considered:	7	4	3	2	3	3		

TABLE 3-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS (Continued)

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
GRASSED SWALES	Ave:	60	20	10	25	70	60	• Runoff Volume • Slope • Soil infiltration rates • Vegetative cover • Swale length • Swale geometry	Yousef, et al, 1985; Dupuis, 1985; Washington State, 1988; Schueler, 1987; British Columbia Res. Corp., 1991; EPA, 1983; Whalen, et al, 1988; Pitt, 1986; Casman, 1990
	Reported Range:	0-100	0-100	0-40	25	3-100*	50-60*		
	Probable Range (4):	20-40	20-40	10-30	--	10-20	10-20		
	No. Values Considered:	10	8	4	1	10	7		
POROUS PAVEMENT	Ave:	90	65	85	80	100	100	• Percolation rates • Storage volume	Schueler, 1987
	Reported Range:	80-95	65	80-85	80	100	100		
	Probable Range:	60-90	60-90	60-90	60-90	60-90	60-90		
	No. Values Considered:	2	2	2	2	2	2		
CONCRETE GRID PAVEMENT	Ave:	90	90	90	90	90	90	• Percolation rates	Day, 1981; Smith, et al, 1981
	Reported Range:	65-100	65-100	65-100	65-100	65-100	65-100		
	Probable Range:	60-90	60-90	60-90	60-90	60-90	60-90		
	No. Values Considered:	2	2	2	2	2	2		
SAND FILTER/FILTRATION BASIN	Ave:	80	50	35	55	60	65	• Treatment volume • Filtration media	City of Austin, 1988; City of Austin, 1990
	Reported Range:	60-95	0-90	20-40	45-70	30-90	50-80		
	Probable Range:	60-90	0-80	20-40	40-70	40-80	40-80		
	No. Values Considered:	10	6	7	3	5	5		

TABLE 3-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS (Continued)

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
WATER QUALITY INLET(7)	Ave:	35	5	20	5	15	5	• Maintenance	Pitt, 1986; Field, 1985; Schueler, 1987
	Reported Range:	0-95	5-10	5-55	5-10	10-25	5-10	• Sedimentation storage volume	
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	No. Values Considered:	3	1	2	1	2	1		
WATER QUALITY INLET WITH SAND FILTER (7)	Ave:	80	NA	35	55	80	65	• Sedimentation storage volume	Shaver, 1991
	Reported Range:	75-85	NA	30-45	45-70	70-90	50-80		
	Probable Range:	70-90	–	30-40	40-70	70-90	50-80	• Depth of filter media	
	No. Values Considered:	1	0	1	1	1	1		
OIL/GRIT SEPARATOR (7)	Ave:	15	5	5	5	15	5	• Sedimentation storage volume	Schueler, 1987
	Reported Range:	0-25	5-10	5-10	5-10	10-25	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10	• Outlet configurations	
	Number of References	2	1	1	1	1	1		
EXTENDED DETENTION DRY POND	Ave:	45	25	30	20	50	20	• Storage volume	MWCOG, 1983; City of Austin, 1991; Schueler and Helfrich, 1988; Pope and Hess, 1988; OWML, 1987; Balt. Dept. P.W., 1989, cited in Schueler et al, 1992
	Reported Range:	5-90	10-55	20-60	0-40	25-65	(-40)-65	• Detention time	
	Probable Range (5):	70-90	10-60	20-60	30-40	20-60	40-60	• Pond shape	
	No. Values Considered:	6	6	4	5	4	5		

TABLE 3-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS (Continued)

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
WET POND	Ave:	70	50	35	50	70	60	• Pool volume • Pond shape	Wotzka and Oberta, 1988; Yousef et al, 1986; Cullum, 1985; Driscoll, 1983; Driscoll, 1986; OWML, 1983; Wu, et al, 1988; Holler, 1987; Martin, 1988; Dorman, et al, 1989; City of Austin, 1990; Horner et al, 1990, Oberts et al, 1989, Bannerman, 1992, cited in Schueler et al, 1992
	Reported Range:	(-35)-99	10-90	5-85	5-90	10-95	10-95		
	Probable Range:	50-99	20-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	24	23	11	11	20	17		
EXTENDED DETENTION WET POND	Ave:	80	65	55	NA	40	20	• Pool volume • Pond shape • Detention time	Ontario Ministry of the Environment, 1991, cited in Schueler et al, 1992
	Reported Range:	50-100	50-80	55	NA	40	20		
	Probable Range:	50-95	50-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	3	3	1	0	1	1		
CONSTRUCTED STORMWATER WETLANDS	Ave:	65	25	20	50	65	35	• Storage volume • Detention time • Pool Shape • Wetland's biota • Seasonal Variation	Harper, et al, 1986; Brown, 1985; Wotzka and Obert, 1988; Hickock, et al, 1977; Barten, 1987; Melorin, 1986; Morris, et al, 1981; Sherberger and Davis, 1982; ABAG, 1979; Oberts, et al, 1989; Rushton and Dye, 1990; Hey and Barrett, 1991, Martin and Smoot, 1986; Reinelt et al, 1990, cited in Woodward-Clyde, 1991
	Reported Range:	(-20)-100	(-120)-100	(-15)-40	20-80	30-95	(-30)-80		
	Probable Range (6):	50-90	(-5)-80	0-40	—	30-95	—		
	No. Values Considered:	23	24	8	2	10	8		

*also reported as 90% TSS removed
**also reported as 50% TSS removed
(1) Design Criteria: Storage volume equals 90% ave. runoff volume, completely drain within 72 hours; maximum depth = 8 ft; minimum depth = 2 ft.
(2) Design Criteria: Storage volume equals 90% ave. runoff volume, completely drain with in 72 hours; maximum depth = 8 ft; minimum depth = 3 ft; storage volume = 40% excavated trench volume.
(3) Design Criteria: Flow depth < 0.3 ft., travel time > 5 min.
(4) Design Criteria: Low slope and adequate length
(5) Design Criteria: Min. E.D. time 12 hours
(6) Design Criteria: Minimum area of wetland equal 1% of drainage area
(7) No information was available on the effectiveness of removing grease or oil
NA: Not Available

TABLE 3-3 COST OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS

PRACTICE	LAND REQUIRE-MENT	CONSTRUCTION COST	USEFUL LIFE	ANNUAL O&M	TOTAL ANNUAL COST	REFERENCES
INFILTRATION BASIN	High	Ave: $0.5/ cu. ft. storage Probable Cost: $0.4 - $0.7/cu. ft. Reported Range: $0.2 - $1.2/ cu. ft.	25[(1)]	Ave: 7% of capital cost Reported Range: 3% - 13% of capital cost	$0.03 - $0.05/ cu. ft.	Wiegand, et al, 1986; SWRPC, 1991
INFILTRATION TRENCH	Low	Ave: $4.0/ cu. ft. storage Probable Cost: $2.5 - $7.5/cu. ft. Reported Range: $0.9 - $9.2/ cu. ft.	10[(1)]	Ave: 9% of capital cost Reported Range: 5% - 15% of capital cost	$0.3 - $0.9/cu. ft.	Wiegand, et al, 1986; Macal, et al, 1987; SWRPC, 1991; Kuo, et al, 1988
VEGETATIVE FILTER STRIP	Varies	Established from existing vegetation- Ave: $0 Reported Range: $0 Established from seed- Ave: $400/ acre Reported Range: $200 - $1,000/ acre Established from Seed & Mulch- Ave: $1,500/ acre Reported Range: $800 - $3,500/ acre Established from sod- Ave: $11,300/ acre Reported Range: $4,500 - $48,000/ acre	50*	Natural Succession Allowed to Occur- Ave: $100/ acre Reported Range: $50 - $200/ acre Natural Succession Not Allowed to Occur- Ave: $800/ acre Reported Range: $700 - $900/ acre	Natural Succession Allowed To Occur- Established from- Natural Vegetation: $100/ acre Seed: $125/ acre Seed & Mulch: $200/ acre Sod: $700/ acre Natural Succession Not Allowed To Occur- Established from: Natural Vegetation: $800/ acre Seed: $825/ acre Seed & Mulch: $900/ acre Sod: $1,400/ acre	Schueler, 1987; SWRPC, 1991
GRASSED SWALES	Low	Established from seed: Ave: $6.5/ lin. ft. Reported Range: $4.5 - $8.5/ lin ft. Established from sod: Ave: $20/ lin. ft. Reported Range: $8 - $50/ lin. ft.	50*	Established From Seed or Sod- Ave: $0.75/ lin. ft. Reported Range: $0.5 - $1.0/ lin. ft.	Established From Seed: $1/ lin. ft. Established From Sod: $2/ lin. ft.	Schueler, 1987; SWRPC, 1991
POROUS PAVEMENT	None	Ave: $1.5/ sq. ft.** Reported Range: $1 - $2/ sq. ft.**	10[(3)]	Ave: $0.01/ sq. ft.** Reported Range: $0.01/ sq. ft.**	0.15/ sq. ft.**	SWRPC, 1991; Schueler, 1987
CONCRETE GRID PAVEMENT	None	Ave: $1/ sq. ft.** Reported Range: $1 - $2/ sq. ft.**	20	Ave: (-$0.04)/sq. ft.** Reported Range: (-$0.04)/ sq. ft.**	0.05/ sq. ft.**	Smith, 1981

TABLE 3-3 COST OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS (continued)

PRACTICE	LAND REQUIRE-MENT	CONSTRUCTION COST	USEFUL LIFE	ANNUAL O&M	TOTAL ANNUAL COST	REFERENCES
SAND FILTER/ FILTRATION BASIN	High	Ave: $5/ cu. ft. Probable Cost: $2 - $9/cu. ft. Reported Range: $1 - $11/cu. ft.	25[2]	Ave: Not Available Probable Cost: 7% of construction cost Reported Range: Not Available	$0.1 - $0.8/cu. ft.	Tull, 1990
WATER QUALITY INLET	None	Ave: $2,000/ each Reported Range: $1,100 - $3,000/ each	50	Ave: $30/each[4] Reported Range: $20-40/each[4]	$150/ each	SWRPC, 1991
WATER QUALITY INLET WITH SAND FILTERS	None	Ave: $10,000/ drainage acre Reported Range: $10,000/ drainage acre	50	Ave: Not Available Probable Cost: $100/ drainage acre Reported Range: Not Available	$700/ drainage acre	Shaver, 1991
OIL/GRIT SEPARATOR	None	Ave: $18,000/ drainage acre Reported Range: $15,000 - $20,000/ drainage acre	50	Ave: $20/ drainage acre[4] Reported Range: $5 - $40/ drainage acre[4]	$1,000/ drainage acre	Schueler, 1987
EXTENDED DETENTION DRY POND	High	Ave: $0.5/ cu. ft. storage Probable Cost: $0.09 - $5/cu. ft. Reported Range: $0.05 - $3.2/ cu. ft.	50	Ave: 4% of capital cost Reported Range: 3% - 5% of capital cost	$0.007 - $0.3/cu. ft.	APWA Res. Foundation
WET POND AND EXTENDED DETENTION WET POND	High	Storage Volume < 1,000,000 cu. ft.: Ave: $0.5/ cu. ft. storage Probable Cost: $0.5 - $1/cu. ft. Reported Range: $0.05 - $1.0/ cu. ft. Storage Volume > 1,000,000 cu. ft.: Ave: $0.25/ cu. ft. storage Probable Cost: $0.1 - $0.5/cu. ft. Reported Range: $0.05 - $0.5/ cu. ft	50	Ave: 3% of capital cost Probable Cost: <100,000 cu. ft. = 5% of capital cost >100,000 & <1,000,000 cu. ft = 3% of capital cost >1,000,000 cu. ft. = 1% of capital cost Reported Range: 0.1% - 5% of capital cost	$0.008 - $0.07/cu. ft.	APWA Res. Foundation; Wiegand, et al, 1986; Schueler, 1987; SWRPC, 1991
CONSTRUCTED STORMWATER WETLANDS	High	Ave: Not available Reported Range: Not available	50*	Ave: Not Available Reported Range: Not Available	Not available	

* Useful life taken as life of project, assumed to be 50 years.

** Incremental Cost, i.e. cost beyond that required for conventional asphalt pavement

(1) References indicate the useful life for Infiltration Basins and Infiltration Trenches are between 25-50 and 10-15 years respectively. Due to the high failure rate, infiltrations basins are assumed to have useful life span of 25 years in infiltration trenches are assumed to have useful life span of 10 years.

(2) Since no information was available for useful life of Filtration Basins they were assumed to be similar to Infiltration Basins.

(3) Since no information was available for useful life of Porous Pavement it was assumed to be similar to that of Infiltration Trenches.

(4) Frequency of Cleaning assumed 2 times per year.

Sections 2 and 3 described the most commonly used structural management practices for control of post-development urban runoff. These management practices remove suspended solids and pollutants entrained in runoff that result from activities occurring after development. In addition, many of these practices can reduce post-development volume and peak runoff rates to equivalent or less than pre-development rates. When these management practices are applied throughout a watershed, they decrease pollutant loads and help prevent severe erosion and flooding, which is generally associated with urban development.

4.1 REMOVAL EFFICIENCIES

The effectiveness of the various water runoff treatment management practices were presented in Table 3-2. As can be seen in the table, the reported pollutant removal rates vary greatly based on design, construction maintenance, and site-specific conditions. However, many of the practices, if properly designed, constructed, and maintained, are capably of achieving over 80 percent removal of total suspended solids (TSS).

Pond systems have been widely used for stormwater runoff treatment and can provide moderate to high pollutant removal if properly designed, constructed, and maintained. Pond systems include extended detention dry ponds, wet ponds, extended detention wet ponds, wetlands, and filtration basins. The effectiveness of the pond is dependant on the pond volume, pond shape, and detention time. Ponds often have a long useful life and relatively low maintenance requirements. Enhancements to ponds such as fringe marshes and pond systems can improve the effectiveness of ponds.

In areas where groundwater recharge is desired, and if soils have a high infiltration rate, infiltration devices can be used. Infiltration devices include infiltration basins, infiltration trenches and dry wells, porous pavement, and concrete grid pavers. Properly designed, constructed, and maintained infiltration devices can achieve moderate to high pollutant removal rates. Storage volume is a critical design factor influencing the effectiveness of infiltration basins and trenches. However, infiltration devices are often not maintained and consequently they have a high failure rate within several years of construction.

Runoff from highly impervious, small drainage areas can be treated with water quality inlets, water quality inlets with sand filters, and oil/grit separators. However, the effectiveness of these devices is often low and they are usually not properly maintained.

In low density areas, vegetative filter strips and grassed swales can be used to provide water quality treatment. In order for these devices to be effective, there should be low flow depths and long travel times. When runoff is not concentrated, there are appropriate flow depths and travel times, and they are properly maintained, vegetative filter strips can provide moderate to high removal rates. Grassed swales often provide low to moderate removal rates and typically do not provide adequate treatment by themselves. Grassed swales are usually an element of a management system.

4.2 SERIES OF MANAGEMENT PRACTICES

Series of management practices should be used to achieve high pollutant removal rates. The use of different types of management practices in series provides more pollutant removal than the use of single controls. This is the result of some practices being more effective in removing different types of pollutants than others.

In addition, some management practices will not function properly if the runoff is not treated prior to the practices. An example of this is infiltration devices will quickly clog as coarse sediment enters the infiltration media. Therefore, it is especially important to use practices which trap coarse sediment prior to entering infiltration devices (such as infiltration basins, infiltration trenches, porous pavement) or filtration basins. Possible practices in series include:

- vegetative filter strip prior to infiltration basin or infiltration trench;
- detention pond prior to filtration basin;
- pond prior to constructed wetland;
- water quality inlet prior to any other practice.

4.3 MAINTENANCE

Proper operation and maintenance of structural treatment facilities is critical to their effectiveness in mitigating adverse impacts of urban runoff. The proper installation and maintenance of various BMPs often determines their success or failure (Reinalt, 1992).

Once an urban runoff facility is installed, it should receive thorough maintenance in order to function properly and not pose a health or safety threat. Maintenance should occur at regular intervals, be performed by one or more individuals trained in proper inspection and maintenance of urban runoff treatment facilities, and be performed in accordance with the adopted standards of the State or local government (Ocean County, undated). It is more effective and efficient to perform preventative maintenance on a regular basis that to undertake major remedial or corrective action on an as needed basis (Ocean County, undated).

5.0
RETROFIT

Runoff and pollutant control from existing development is often enhanced through retrofit projects. Retrofit is the process of replacing or recreating stream or watershed's functions that have been lost or damaged as the result of urbanization. (MWCOG, 1989) Retrofits are unique because they are used in areas that have already been urbanized and they are used to reduce existing nonpoint source pollution. In contrast, the practices discussed in the previous sections are built as part of a development and are planned and constructed to eliminated expected nonpoint source pollution.

5.1 DESCRIPTION

This section describes several management practices that are available for retrofit projects. The advantages and disadvantages of the various retrofit projects are similar to those summarized in Table 3-1. Because retrofits are a relatively new area, there are little data available on the effectiveness and cost of retrofits. Retrofit projects include the construction or modification of facilities for removal of pollutants from stormwater runoff, the stabilization of stream banks and channels, and the restoration of riparian buffers and wetlands.

5.1.1 Construction or Modification of Pollutant Removal Facilities

Many of the management practices discussed in Sections 2 through 4 of this report cannot be used in already urbanized areas because they require space that is not typically available in urbanized areas. However, two types of pollutant removal retrofits can be used. New facilities can be built in limited land space and existing facilities can be modified to obtain increased water quality benefits.

5.1.1.1 New Facilities

If there is space available, the management practices discussed in Section 2 through 4 can be constructed to provide water quality benefits. However, there are often space constraints in urbanized areas that will not allow construction of these facilities. One option available for these circumstances is water quality inlets. They can be constructed in highly impervious areas such as parking lots. The effectiveness and costs of these facilities would be similar to those previously discussed.

- Water Quality Inlets - There are several types of water quality inlets - catch basins, catch basins with sand filters and oil-grit separators. These are discussed in detail in Sections 2 through 4.

5.1.1.2 Revise Existing Facilities

In the past many stormwater management facilities were constructed to provide peak volume control. However, most of these facilities provide minimal water quality benefits. These existing facilities can be modified to provide water quality benefits. Two common modification can be dry pond conversions and fringe marsh creations.

- Dry Pond Conversion- Many stormwater management dry ponds have been constructed that provide peak volume control, but provide minimal water quality benefits. Many of these ponds can be relatively easily modified to provide water quality control. These modifications can include decreasing the size of the outlet to increase the detention of the dry pond. This creates an extended detention dry pond similar to that discussed in Sections 2 through 4. Also, a dry pond's outlet can also be modified to detain a permanent pool of water and thus create a wet pond or extended detention wet pond.

- Fringe Marsh Creation- Aquatic vegetation can be planted along the perimeter of constructed wet ponds or other open water systems to enhance biological pollutant uptake.

5.1.2 Stabilize Shorelines, Stream Banks and Channels

Urbanization can significantly increase the volume and velocity of stormwater runoff that can severely erode stream banks and channels. This erosion can create high sediment loads in coastal receiving water. Stream banks can be stabilized by providing plantings along the stream bank, or placing boulders, rip-rap, retaining walls or other structural controls in eroding areas.

Where feasible, vegetation and other soft practices should be used instead of hard, structural practices.

5.1.3 Protect And Restore Riparian Forest And Wetland Areas

Riparian forests and wetlands are very effective water quality controls. Consequently, they should be protected and restored wherever possible. Riparian forest can be restored by replanting the banks and floodplains of a stream with native species to stabilize erodible soils and improve surface and groundwater quality.

5.2 EFFECTIVENESS

The effectiveness of retrofit water quality facilities is similar to that discussed in Section 2.2 and shown in Table 3-2. The effectiveness of revising existing facilities will depend on the constraints of the existing facility. If sufficient storage volume is available, a dry pond that is converted into an extended detention dry pond or wet pond could provide removal rates similar to those discussed in Section 2.2.

Stabilizing stream banks and channels can reduce their erosion and therefore reduce the sediment loads entering the water body. Protecting and restoring riparian forest and wetland areas provides a natural area of very effective water quality control.

Table 5-1 summarizes the effectiveness of retrofit projects.

5.3 COST

The use of retrofits is relatively new and therefore there is very limited information on its costs. The cost of retrofit water quality inlets is higher than the costs reported for developing areas since existing inlets and pavement would have to be removed to install water quality inlets in already developed areas. The cost of converting dry ponds into extended detention dry ponds, wet ponds, and extended detention wet ponds should be substantially less than the cost to construct these structures in developing areas since it typically only requires minimal modifications to the existing facility.

TABLE 5-1 - EFFECTIVENESS OF EXISTING DEVELOPMENT MANAGEMENT PRACTICES

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
WATER QUALITY INLET - CATCH BASIN (1)	Ave:	15	5	5	5	15	5	• Maintenance • Sedimentation storage volume	Pitt, 1986; Field, 1985; Schueler, 1987
	Reported Range:	10-95	5-10	5-10	5-10	10-55	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	No. Values Considered:	2	1	1	1	3	1		
WATER QUALITY INLET - CATCH BASINS WITH SAND FILTER (1)	Ave:	80	NA	35	55	80	65	• Sedimentation storage volume • Depth of filter media	Shaver, 1991
	Reported Range:	75-85	NA	30-45	45-70	70-90	50-80		
	Probable Range:	70-90	--	30-40	40-70	70-90	50-80		
	No. Values Considered:	1	0	1	1	1	1		
WATER QUALITY INLET - OIL/GRID SEPARATOR (1)	Ave:	15	5	5	5	15	5	• Sedimentation storage volume • Outlet configurations	Schueler, 1987
	Reported Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	Number of References	1	1	1	1	1	1		
DRY POND MODIFIED INTO ED DRY POND	Ave:	45	25	35	20	45	20	• Storage volume • Detention time • Pond shape	MWCOG, 1983, City of Austin, 1991; Schueler and Helfrich, 1988; Pope and Hess, 1988; OWML, 1987; Balt. Dept. P.W., 1989, cited in Schueler et al, 1992
	Reported Range:	5-90	10-55	20-60	0-40	25-65	(-40)-65		
	Probable Range (2):	70-90	10-60	20-60	30-40	20-60	40-60		
	No. Values Considered:	6	6	4	5	4	5		

TABLE 5-1. EFFECTIVENESS OF EXISTING DEVELOPMENT MANAGEMENT PRACTICES (Continued)

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
DRY POND MODIFIED INTO WET POND	Ave:	70	50	35	50	70	60	• Pool volume • Pond shape	Wetzka and Oberta, 1988; Yoosef et al., 1986; Collum, 1985; Driscoll, 1983; Driscoll, 1986; OWML, 1983; Wu et al., 1988; Holter, 1987; Martin, 1988; Darmay et al., 1989; Horner et al, 1990; Oberts et al, 1989; Bannerman, 1992; City of Austin, 1990, cited in Schueler et al, 1992
	Reported Range:	(-30)-99	10-90	5-85	5-90	10-95	10-95		
	Probable Range:	50-99	20-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	24	23	11	11	20	17		
DRY POND OR WET POND MODIFIED INTO ED WET POND	Ave:	80	65	55	NA	40	20	• Pool volume • Pond shape • Detention time	Ontario Ministry of the Environment, 1991, cited in Schueler et al, 1992
	Reported Range:	50-100	50-80	55	NA	40	20		
	Probable Range:	50-95	50-80	—	—	—	—		
	No. Values Considered:	1	1	1	0	1	1		
STREAMBANK STABILIZATION	Ave:	NA	NA	NA	NA	NA	NA		MWCOG, 1990
	Reported Range:	NA	NA	NA	NA	NA	NA		
	Probable Range:	--	--	--	--	--	--		
	No. Values Considered:	0	0	0	0	0	0		
RIPARIAN FOREST (assumed same as Vegetative Filter Strip)	Ave:	70	50	60	70	20	50	• Runoff volume • Slope • Soil infiltration rates • Vegetative cover • Buffer length	IEP, 1991; Casman, 1990; Glick et al., 1991; VA Dept. of Cons., 1987; Minnesota PCA, 1989; Schueler, 1987; Hartigen et al., 1989
	Reported Range:	20-80	30-95	40-70	60-80	20*	50**		
	Probable Range (3):	40-90	30-80	20-60	--	30-80	20-50		
	No. Values Considered:	6	3	2	1	2	2		

TABLE 5-1. EFFECTIVENESS OF EXISTING DEVELOPMENT MANAGEMENT PRACTICES (Continued)

MANAGEMENT PRACTICE		% REMOVAL						MAIN REMOVAL EFFICIENCY FACTORS	REFERENCES
		TSS	TP	TN	COD	Pb	Zn		
WETLAND (assumed same as Constructed Stormwater Wetlands)	Ave:	65	25	20	50	65	35	• Storage volume • Detention time • Pool Shape • Wetland's biota • Seasonal Variation	Harper et al., 1986; Brown, 1985; Wotzka and Obert, 1988; Hickack et al., 1977; Barten, 1987; Meloria, 1986; Morris et al., 1981; Sherberger and Davis, 1982; ABAG, 1979; Oberts et al., 1989; Rushton and Dye, 1990; Hey and Barrett, 1991; Martin and Smoot, 1986; Reinelt et al, 1990, cited in Woodward-Clyde, 1991
	Reported Range:	(-20)-100	(-120)-100	(-15)-40	20-80	30-95	(-30)-80		
	Probable Range (6):	50-90	(-5)-80	0-40	—	30-95	—		
	No. Values Considered:	14	14	6	2	6	4		

6.0
REFERENCES

APWA Research Foundation. n.d. "Costs of Stormwater Management Systems." Urban Stormwater Management. APWA.

Bassler, R.E. n.d. Grassed Waterway Maintenance. Agricultural Engineering Department/ University of Maryland.

British Columbia Research Corporation. 1991. Urban Runoff Quality and Treatment: A Comprehensive Review. Greater Vancouver Regional District.

Cahill, T.H., W.R. Horner, J. McGuire and C. Smith. October 25, 1991. Interim Report: Infiltration Technologies - Draft. Cahill Associates prepared for USEPA, NPSCB, Washington, DC.

Casman, E. 1990. Selected BMP Efficiencies Wrenched from Empirical Studies. Interstate Commission on Potomac River Basin.

City of Austin Environmental Resource Management Division; Environmental and Conservation Services Department. 1990. Removal Efficiencies of Stormwater Control Structures. Environmental Resource Management, Austin, Texas.

City of Austin. 1988. Inventory of Urban Nonpoint Source Pollution Control Practices.

Day, G., D.R. Smith, and J. Bowers. 1981. Runoff and Pollution Abatement Characteristics of Concrete Grid Pavements. Virginia Water Resources Research Center/ Virginia Polytechnic Institute.

Dorman, M.E., J. Hartigan R.F. Steg, and T. Quasebarth. August 1989. Retention, Detention and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume I. Research Report. FHWA.

Dupuis, T.V. and N.P. Kobriger. July 1985. Effects of Highway Runoff on Receiving Waters. Volume IV: Procedural Guidelines for Environmental Assessments. FHWA. Report No. FHWA/RD-84/065.

Field, R. 1985. "Urban Runoff: Pollution Sources, Control,and Treatment." Water Resources Bulletin. Vol. 21, No. 2. American Water Resource Association.

Finnemore, J.E. October 1982. Stormwater Pollution Control: Best Management Practices. ASCE.

Glick, R., M.L. Wolfe, and T.L. Thurow. 1991. Urban Runoff Quality As Affected By Native Vegetation. Presented at the 1991 International Summer Meeting sponsored by ASAE. (Albuquerque, New Mexico). ASAE Paper No. 91-2067.

Hartigan, J.P., T.S. George, T.F. Quasebarth and M.E. Dorman. 1989. Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Vol. II Design Guidelines. FHWA. Report No. FHWA/RD-89/203.

IEP, Inc. 1991. Vegetated Buffer Strip Designation Method Guidance Manual. Narragansett Bay Project. USEPA and RI DEM.

Kuo, C.Y., K.A. Cave and G.V. Loganathan. 1988. "Planning of Urban Best Management Practices." Water Resources Bulletin. American Water Resources Association.

Lindsey G., L. Roberts and W. Page. June 1991. Stormwater Management Infiltration Practices in Maryland: A Second Survey. MD Department of the Environment, Sediment and Stormwater Administration.

Livingston, E. and E. McCarron, J. Cox, and P. Sazone. 1988. The Florida Development Manual: A Guide to Sound Land and Waste Management. Florida Department of Environmental Regulation.

Lugbill, J. 1990. Potomac River Basin Nutrient Inventory. MWCOG.

Macal, C.M., and B.J. Broomfield. 1980. Costs and Water Quality Effects of Controlling Point and Nonpoint Pollution Sources. National Science Foundation, Argonne National Laboratory (USDOE).

Metropolitan Washington Council of Governments. 1989. State of the Anacostia - 1989 Status Report. MWCOG.

Minnesota Pollution Control Agency. 1989. Protecting Water Quality in Urban Areas

Ocean County. Date Unknown. Ocean County Demonstration Study: Stormwater Management Facilities Maintenance Manual.

Pitt, R. 1986. "Runoff Controls in Wisconsin's Priority Watersheds." Urban Runoff Quality - Impact and Quality Enhancement Technology. Proceeds of an Engineering Foundation Conference. (Henniker, NH, June 23-27, 1986.) ASCE. pp. 290-313.

Pitt, R. and G. Shalwly. June 1981. San Francisco NURP Project: NPS Pollution Management on Castro Valley Creek. USEPA and ABAG.

Puget Sound Water Quality Authority. June 1989. Managing Nonpoint Pollution - An Action Plan Handbook for Puget Sound Watersheds.

Schueler, T. December 9, 1992. Performance and Longevity of Urban BMP Systems. Presented at ASCE Continuing Education Seminar "How to Implement Stormwater Best Management Practices."

Schueler, T., P. Kumble, and M. Heraty. March, 1992. A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. MWCOG.

Shaver, E. 1991. Sand Filter Design for Water Quality Treatment. Presented at 1991 ASCE Stormwater Conference in Crested Butte, Colorado.

Silverman , G.S. and M.K. Stenstrom. 1988. "Source Control of Oil and Grease in an Urban Area." Design of Urban Runoff Quality Controls. Proceedings of an Engineering Foundation Conference. Potosi, Missouri. July 10-15, 1988. ASCE. pp. 403-420.

Smith, D.R., M.K. Hughes, and D.A. Sholtis. May 30, 1981. Green Parking Lot Dayton, Ohio - An Experimental Installation of Grass Pavement. City of Dayton, Ohio.

Southeastern Wisconsin Regional Planning Commission. June 1991. Costs of Urban Nonpoint Source Water Pollution Control Measures. Technical Report Number 31.

Tull, L. 1990. Cost of Sedimentation/Filtration Basins. City of Austin.

U.S. EPA. 1983. Final Report of the Nationwide Urban Runoff Program. Water Planning Division.

Virginia Department of Conservation and Historic Resources, DSWC. 1987. Chesapeake Bay Research/Demonstration Project Summaries July 1, 1984 - June 30, 1985. VA DCHR.

Washington State Department of Transportation/University of Washington. March 1988. Washington State DOT Highway Water Quality Manual. Chapters 1 and 2. WSDOT.

Whalen, P. and M.G. Cullum. 1988. An Assessment of Urban Land Use/Stormwater Runoff Quality Relationships and Treatment Efficiencies of Selected Stormwater Management Systems. South Florida Water Management District Resource Planning Dept.; Water Quality Division. Technical Publication No. 88-9.

Wiegand C., T. Schueler, W. Chitterden, D. Jellick. 1986. "Cost of Urben Runoff Quality Controls." Urban Runoff Quality - Impact and Quality Enhancement Technology. Proceedings of an Engineering Foundation Conference. (Henniker, NH, June 23-27, 1986.) ASCE. pp. 366-380.

Woodward-Clyde. 1991. The Use of Wetlands for Controlling Stormwater Pollution. EPA Region 5.

Woodward-Clyde. 1989. Analysis of Storm Event Characteristics for Selected Rainfall Gages Throughout the United States.

Woodward-Clyde. 1986. Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality. Prepared for Office of Water, NPS Division, USEPA, Wash., D.C.

Young, G.K. and D. Danner. March 1982. Urban Planning Criteria for Non-Point Source Water Control.

Yousef, Y.A., M.P. Wanielista, H.H. Harper, D.B. Pearce and R.D. Tolbert. July 1985. Best Management Practices - Removal of Highway Contaminants by Roadside Swales. Final Report. Florida Department of Transportation.

APPENDICES

APPENDIX A

STATE REGULATIONS

STATE STORMWATER MANAGEMENT/BMP REGULATIONS[1]

State/Region	Regulation/Guidelines*	Where Required	Storm for which post-develop. peak runoff rate must be equal or less than pre-develop.	Required Pollutant Removal	Volume of Water Required for Quality Treatment
Alabama	No state law	---	---	---	---
Alaska	No state law	---	---	---	---
American Samoa	No state law	---	---	---	---
California	No state law	---	---	---	---
Connecticut	No state law	---	---	---	---
Delaware	Sediment and Stormwater Regulations	Statewide for sites greater than 5,000 sf	both 2 year - 24 hour and 10 year - 24 hour	80% suspended solids	1/2" runoff
Florida	Stormwater Discharge Regulations of 1982	Statewide for sites requiring permits	No statewide requirement	80% total annual pollutant load	No statewide requirement
Guam	No state law	---	---	---	---
Hawaii	No state law	---	---	---	---
Louisiana	No state law	---	---	---	---
Maine	No state law	---	---	---	---
Maryland	Stormwater Management Regulations of 1984	Statewide for sites greater than 5,000 sf	both 2 year - 24 hour and 10 year - 24 hour	What is achieved by using the BMPs from the preferred BMP list	1/2" runoff

[1]This information is based on telephone contacts completed in 1991.
The state regulations should be consulted for current requirements.

STATE STORMWATER MANAGEMENT/BMP REGULATIONS[1]

State/Region	Regulation/Guideline*	Where Required	Storm for which post-develop peak runoff rate must be equal or less than pre-develop	Required Pollutant Removal	Volume of Water Required for Quality Treatment
Massachusetts	No state law	---	---	---	---
Michigan	No state law	---	---	---	---
Minnesota**	Metropolitan Surface Water Management Law and Comprehensive Local Water Management Act	Mandatory in the 7 metropolitan counties and voluntary for the remaining counties.	No statewide requirement	No statewide requirement	No statewide requirement
Mississippi	No state law	---	---	---	---
New Hampshire	Water Supply and Waste Disposal Law	Statewide for sites greater than 100,000 sf	10 year - 24 hour		
New Jersey- Coastal Zone	Coastal Zone Management Rules of 1980	For areas requiring coastal permits	both 2 year - 24 hour and 10 year - 24 hour	No statewide requirement	1 year - 24 hour storm or 1 1/4" rainfall
New York	No state law	---	---	---	---
North Carolina	Administrative Code	In coastal counties 1/4 acre to 1/3 acre	---	---	1" rainfall
Northern Mariana Island	No state law	---	---	---	---
Ohio**	No state law	---	---	---	---

[1]This information is based on telephone contacts completed in 1991.
The state regulations should be consulted for current requirements.

STATE STORMWATER MANAGEMENT/BMP REGULATIONS[1]

State/Region	Regulation/Guideline	Where Required	Storm for which post-development peak runoff rate must be equal or less than pre-develop.	Required Pollutant Removal	Volume of Water Required for Quality Treatment
Oregon	No state law	---	---	---	---
Pennsylvania	No state law	---	---	---	---
Puerto Rico	No state law	---	---	---	---
Rhode Island	Design and Installation Standards for Stormwater BMPs (will be incorporated into wetland laws, expected Dec. 1991)	Wherever coastal or wetland permit required	both 2 year, 10 year and 100 year	Recommended TSS removal rate of 80%	Recommended 1" per impervious acre
South Carolina - Coastal Zone	South Carolina Coastal Council Stormwater Management Guidelines	For some sites within coastal zone	5 year - 24 hour	No statewide requirement	1" rainfall
Virgin Islands	No state law	---	---	---	---
Virginia -	Stormwater Management Act of 1989	Mandatory for state sponsored development, voluntary elsewhere	both 2 year - 24 hour and 10 year - 24 hour	No statewide requirement	1/2" runoff
Virginia - Chesapeake Bay	Chesapeake Bay Act	For sites greater than 2,500 sf in Chesapeake Bay Preservation Areas	both 2 year - 24 hour and 10 year - 24 hour	No net increase in NPS pollution. For redevelopment- 10% reduction in NPS loads	1/2" runoff
Washington	No state law	---	---	---	---
Wisconsin	Water Pollution Law (permit process being developed)	Statewide for sites greater than 3 acres	both 2 year and 10 year	What is achieved by using BMP from the preferred BMP list	What is required in the preferred BMP list

*Does not include state water quality standards
** Awaiting Coastal Zone Approval

[1]This information is based on telephone contacts completed in 1991.
The state regulations should be consulted for current requirements.

APPENDIX B

EFFICIENCY DATA

MANAGEMENT PRACTICE FOR URBAN STORMWATER RUNOFF

Infiltration Basin
Infiltration Trench
Vegetative Filter Strip (VFS)
Grassed Swale
Porous Pavement
Concrete Grid Pavement
Filtration Basins
Water Quality Inlet - Catch Basin
Water Quality Inlet - Catch Basin with Sand Filter
Water Quality Inlet - Oil/Grit Separators
Dry Extended Detention Ponds*
Wet Ponds*
Wet Extended Detention Ponds*
Stormwater Wetlands*
Extended Detention Wetlands*
Natural Wetlands*
Pond/Wetland Systems*
Wetlands

*Compiled by Metropolitan Washington Council of Governments

Mangement Practice: INFILTRATION BASIN

DESCRIP-TION	LOCA-TION	WATERSHED AREA (acres)	TREATMENT VOL.	INFIL-TRATION RATE (in./hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Infiltration Basin	DC	5 ac. minimum, 20 ac. maximum	Complete 2 yr runoff volume	0.27 minimum	99	65-75		60-70					BAC: 98 BOD: 90 TM: 95-99	From field testing of similar rapid infiltration land treatment systems	NVPDC, 1979 and EPA, 1977 cited in Schueler, 1987
Infiltration Basin	DC	5 ac. minimum, 50 ac. maximum	runoff from 1 in. storm	0.27 minimum	90	60-70		55-60					BAC: 90 BOD: 80 TM: 85-90	From modeling studies and field studies	NVPDC, 1979 and Griffin, et al, 1980 cited in Schueler, 1987
Infiltration Basin	DC	5 ac. minimum, 50 ac. maximum	0.5 in. runoff /impervious acre	0.27 minimum	75	50-55		45-50					BAC: 75 BOD: 70 TM: 75-80	From modeling studies and field studies	NVPDC, 1979 and Griffin, et al, 1980 cited in Schueler, 1987
Recharge Device	Great Lakes	Efficiency independent of watershed area	109 cf./ac.	6.0	45	45	45	45	45	45	45	45		Read from chart developed from NURP data analysis	EPA, 1983
Recharge Device	DC	Efficiency independent of watershed area	Runoff from 1 in. storm	0.5 to 8.27	75-98	75-98	75-98	75-98	75-98	75-98	75-98	75-98		From model	Woodward-Clyde, 1986
Recharge Device	DC	Efficiency independent of watershed area	0.5 in. runoff/imper. acre	0.5 to 8.27	55-90	55-90	55-90	55-90	55-90	55-90	55-90	55-90		From model	Woodward-Clyde, 1986
Recharge Device	Great Lakes	Efficiency independent of watershed area	109 cf./ac.	6.0	50	50	50	50	50	50	50	50		From model	Woodward-Clyde, 1986

Management Practice: **INFILTRATION TRENCH**

DESCRIPTION	LOCATION	WATERSHED AREA (Acres)	TREATMENT VOL.	INFILTRATION RATE (In./Hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Infiltration trench	DC	5 ac max	Complete storm volume	0.27 minimum	99	65-75		60-70					BAC: 98 BOD: 90 TM: 95-99	From field testing of similar rapid infiltration land treatment systems	NVPDC, 1979 and EPA, 1977 cited in Schueler, 1987
Infiltration trench	DC	5 ac max	runoff from 1 in. storm	0.27 minimum	90	60-70		55-60					BAC: 90 BOD: 80 TM: 85-90	From modeling studies and field studies	NVPDC, 1979 and Griffin, et al, 1980 cited in Schueler, 1987
Infiltration trench	DC	5 ac max	0.5 in. runoff/ impervious acre	0.27 min	75	50-55		45-55					BAC: 75 BOD: 70 TM: 75-80	From modeling studies and field studies	NVPDC, 1979 and Griffin, et al, 1980 cited in Schueler, 1987
Infiltration trench	NA	NA	NA	NA	96	41		61					BOD: 84	NA	Biggers, et al, 1980 and USEPA, 1983 cited in Kuo, et al, 1988
Infiltration trench	NA	NA	NA	NA	50	60		(-8)						NA	NURP, 1983 cited in Lugbill, 1990
Recharge Device	Great Lakes	Efficiency independent of watershed area	109 cf./ac.	6.0	45	45	45	45	45	45	45	45		Read from chart developed from NURP data analysis	EPA, 1983
Recharge Device	DC	Efficiency independent of watershed area	Runoff from 1 in. storm	0.5 to 8.27	75-98	75-98	75-98	75-98	75-98	75-98	75-98	75-98		From model	Woodward-Clyde, 1986

Management Practice: **INFILTRATION TRENCH**

DESCRIPTION	LOCATION	WATERSHED AREA (Acres)	TREATMENT VOL.	INFILTRATION RATE (In./Hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Recharge Device	DC	Efficiency independent of watershed area	0.5 in. runoff/imper. acre	0.5 to 8.27	55-90	55-90	55-90	55-90	55-90	55-90	55-90	55-90		From model	Woodward-Clyde, 1986
Recharge Device	Great Lakes	Efficiency independent of watershed area	109 cf./ac.	6.0	50	50	50	50	50	50	50	50		From model	Woodward-Clyde, 1986

Management Practice: **VEGETATIVE FILTER STRIP (VFS)**

DESCRIPTION	LOCATION	WATERSHED AREA (ac)	VFS SLOPE	VFS LENGTH	POLLUTANT REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Vegetative buffer	RI	NA	NA	NA	See Chart									Based on multiple simulations of pollutant (TSS) generation, transport & removal for buffer strips under various site conditions using the P8 urban catchment model.	IEP, 1991
Vegetative filter		NA	2.5%	85'	Dropped from 80% to 50% in 1 season Varied from 20-80% Ave= 53%									16 month study for sediment control	Hayes & Hairston, 1983 cited in Casman, 1990
Orchard grass buffer	Virginia	NA	NA	31'	70-98	65-95	(-192)-70	66						Monitored test plots, no information on pollution source	Dillaha, et al, 1989 cited in Glick, et al, 1991
Bluegrass sod buffer		NA	NA	4'	78									Pollutant source - up slope bare soil	Neibling and Alberts, 1979 cited in Glick, et al, 1991

Management Practice: **VEGETATIVE FILTER STRIP (VFS)**

DESCRIPTION	LOCA-TION	WATER-SHED AREA (ac)	VFS SLOPE	VFS LENGTH	POLLUTANT REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Grass level spreader	Virginia	NA	NA	70'	70 (Increasing length from 70' to 150' increased removal rates only minutely)	28					20	51	NN:11	Monitored March to June '87 - 8 storms, Pantops Shopping Center, Charlottesville, VA	VA Dept. of Cons., 1987
Filter strip-properly designed and operated	Minn.	NA	NA	NA	30-50										Nonpoint Source Control Task Force, 1983 cited in Minnesota PCA, 1989
Turf strip	D.C.	NA	NA	20'	20-40	0-20		0-20		0-20			TM: 20-40		Schueler, 1987
Forested strip with level spreader	D.C.	NA	NA	100'	80-100	40-60		40-60		60-80			TM: 80-100		Schueler, 1987
VFS- Source parking lot		NA	NA	NA	Buffer not effective in reducing pollutant. Preliminary study, final conclusions not yet reached, but prelim indicates buffer not effective for urban runoff. Possible reasons, 1) conc. in urban runoff significantly lower than agricult. or forest 2) urban runoff has excess transport capacity when entering buffer and detaches sediment and adsorbed pollutants with no deposition occurring.										Glick, et al, 1991
Vegetative Control		NA	NA	NA	See Chart						90% of TSS removal	50 % of TSS removal	CU:60% of TSS removal	Generated from research, see grass swales along highways table	Hartigan, et.al., 1989
Agriculture VFS		NA	NA	NA	o Effectiveness of VFS decreases with time as sediment accumulates within it unless the vegetation can grow as fast as it is being buried. o VFS more effective in removing SS than nutrients o Effectiveness of VFS highly dependent on condition of filter										Casman, 1990

Management Practice: **VEGETATIVE FILTER STRIP (VFS)**

DESCRIPTION	LOCATION	WATERSHED AREA (ac)	VFS SLOPE	VFS LENGTH	POLLUTANT REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Agriculture vegetated filter.	D.C.	NA	11%	30'	95	80		70	4				NH4: 69 TKN: 80 PO4: 30	Runoff from Agriculture feed lot, storm simulated- 2 year in Potomac Region. Did not capture change in filter efficiency over period of time. 2 test runs separated by 7 days	Dillah et al, 1988 cited in Casman, 1990
		NA	11%	15'	87	63		61	-36				NH4: 34 TKN: 64 PO4: -20		
		NA	16%	30'	88	57		71	17				NH4: -35 TKN: 72 PO4: -51		
		NA	16%	15'	76	52		67	3				NH4: -21 TKN: 69 PO4: -108		
Agriculture, VFS on sandy loam	MD	NA	3%	30'	82	42		Runoff: 41 Leachate: 87 Total: 83						Agriculture study, 3 simulated storms over 3 weeks during growing season. Subsurface leaching loss important component of inorganic N movement from agricultural areas	Magette, 1987 cited in Casman, 1990
		NA	4%	30'	82	25		Runoff: 48							
		NA	5%	30'	86	52		Runoff: 51 Leachate: 3 Total:11							
		NA	3%	15'	65	22		Runoff: -15 Leachate:-10 Total:-20							
		NA	4%	15'	66	27		Runoff:-6							

Management Practice: **VEGETATIVE FILTER STRIP (VFS)**

DESCRIPTION	LOCATION	WATERSHED AREA (ac)	VFS SLOPE	VFS LENGTH	POLLUTANT REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
		NA	5%	15'	72	41		Runoff: -17 Leachate: 39 Total:36							
Agriculture, mixture rye, fescues and bluegrass on loam soil:		NA												Measured surface and subsurface leaving site over 2 years. Parlor waste discharged 2 times a day.	Schwer & Clausen, 1989 cited in Casman, 1990
Surface Runoff Only:			2%	85'	99	94							OP:98 TKN: 99 NH4: 88		
Surface and Groundwater:			2%	85'	95	84							OP:92 TKN: 92 NH4:78		
Seasonal Efficiency				Snow-melt		35							TKN: 57		
				Winter		95							TKN: 94		
				Growing		96							TKN: 98		
				Spring/Fall		96							TKN: 94		
				o As loading rates increase, efficiency decreases											

Management Practice: **GRASSED SWALE**

DESCRIPTION	LOCATION	SLOPE	LENGTH (FT)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
				TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Low vegetation density & height	DC	2-6%	NA	No significant water quality benefit measured, but report concluded that if residence time and infiltration capability increased, then could be effective BMP									Study 3 swales, NURP at Wash. DC suburbs	Schueler, 1987; British Columbia Res. Corp., 1991; and EPA, 1983
Grassed swale with no check dams	DC	high	NA	0-20	0-20		0-20					TM: 0-20 OD: 0-20		Schueler, 1987
Grassed swale with check dams	DC	low	NA	20-40	20-40		20-40					TM: 0-20 OD: 20-40		Schueler, 1987
Swale in low density residential	FL	NA	NA	99+	99+					99+		TKN: 99+ BOD: 99	Monitoring study in Brevard Co, Florida	Post, et al 1982 cited in Whalen, et al, 1988
Swale for commercial parking lot designed to provide surface detention, with a clay layer placed below top soil layer to prevent infiltration	NH	low	NA		Negli-gible	Negli-gible			25	50-65	50	TKN: 28 BOD: 11 Cu: 48 Cd: 42 NH3: 25-51 ON: Not sig. NN: 32	Monitoring study in Durham, NH; Over 11 storms monitored in Durham, NH as part of NURP.	Oakland, 1983, and Athayde, et al 1983 cited in Whalen, et al, 1988; Schueler, 1987; EPA, 1983; British Columbia Res. Corp, 1991
Swales	NA	NA	NA	Pollutants may reach ground water and discharge indirectly into receiving water										Whalen, et al, 1988

Management Practice: **GRASSED SWALE**

DESCRIPTION	LOCATION	SLOPE	LENGTH (FT)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
				TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Swale	NA	NA	NA	80						80	60	Cu: 60	Compiled from literature	Horner, 1988 cited in British Columbia Res. Corp, 1991
Vegetative Control	*	*	*	See Chart						90% of TSS removal	50% of TSS removal	Cu: 60% of TSS removal	*Generated from research, see grass swales along highways table	Hartigan, et al, 1989
Roadside drainage system - grass swales.	Toronto residential	NA	NA							Warm Weather Storm Water: 90 Cold Weather Melt Water: 13 Weighted Total Annual: 28		Warm Weather Storm Water / Cold Weather Melt Water / Weighted Total Annual Flow: 90 13 20	Monitoring conducted 1984-1985. 100 rains. 50 snowmelts monitored.	Pitt and Mclean, 1986 cited in Pitt, 1986
Agricultural vegetated, 1 foot channel, 4% cross slope	DC	5%	30'length	58	19		7	-158				NH4:-11 TKN:9 PO4:31	Runoff from Agr. feedlot, storm simulated 2 yr in POtomac Region. Did not capture change in filter efficiency o er time. 2 test runs separated by 7 days.	Dillaha et al, 1988 cited in Casman, 1990
			15' length	31	2		0	-82				NH4:1 TKN:1 PO4:-3		

Management Practice: **GRASSED SWALES ALONG HIGHWAYS**

DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	SLOPE	LENGTH (FT)	REMOVAL EFFICIENCY (%) TSS	TP	TKN	Pb	Zn	Cr	Ni	Cu	OTHER	STUDY TYPE	REFERENCE
Grass swale along I-4 @ Maitland	Florida	NA	0.8%	160				91%	90%	44%	88%	41%		17 storm events, 8 month period. Removal efficiencies vary by storm	Yousef, et al, 1985
Grass swale along I-5 @ NE 158th ADT = 100,000 veh	Washington	NA		220	80%			83%	69%			63%			Horner, 1982 cited in Dupuis, 1985
Grass swale along:															Hartigan, et al 1989
I-4 @ South Orange Blossom Trail	Florida	0.56 ac/ 63% imperv.	<3.5%	200	87-98%	-47 to +26%	13-51%	33-94%	69-81%	29-65%		42-78%	NOx: 12-52% TOC: 58-66%	13 storms monitored	
I-66	Virginia	1.27 ac/ 67% imperv.	4.7%	200	52-65%	36-41%	17-26%	17-78%	27-49%	-34 to +16%		12-28%	NOx: 2-11% TOC: 29-76%	12 storms monitored	
I-270	Maryland	NA	3.2%	200		-33 to +12%	3-46%	8-98%	18-47%	5 - 83%		-43 to +22%	Nox: -28 to -143%	4 storms monitored	
	Removal of metals correlated with TSS removal. Nutrient removal varies widely, appears unrelated to TSS removal. Results suggest that not only channel lengths, but also channel slope and channel geometry (to reduce flow depth) also contribute to TSS removal, and metals removal														
Grass lined channel, flow depth less than 6 inches	Washington	NA	< 8%	200	80%			80%					COD: 80%		Washington State, 1988

Management Practice: **POROUS PAVEMENT**

DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In/Acre)	INFIL-TRATION RATE (In/Hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Porous pavement - partial exfiltration	Rockville, MD	NA	NA	NA	95	65		85		82	98	99		Pollutant export over series of storms monitored at a terminal underdrain and compared to runoff from adjacent conventional pavement	OWML, 1983, 1986 cited in Schueler, 1987
Porous Pavement - partial exfiltration	Prince William, VA	NA	NA	NA	82	65		80						Pollutant export over series of storms monitored at a terminal underdrain and compared to runoff from adjacent conventional pavement	OWML, 1983, 1986 cited in Schueler, 1987

Management Practice: **CONCRETE GRID PAVEMENT**				
DESCRIPTION	LOCATION	REMOVAL EFFICIENCY (%) REDUCTION IN STORM RUNOFF	STUDY TYPE	REFERENCE
3 types of grid pavements: lattice, castellated and poured-in place pavers, all at 4% slope	Lab	98.7 TO 100	Lab setting. Runoff volume and pollution reduction associated for 10 simulated rainfall events and most with return period of less than 10 years	Day, 1981
Lattice papers (turfstone)	Downtown municipal parking lot Dayton, Ohio	65 to 97	Monitoring study for a period of 10 weeks for 11 rain fall events with return period of less than 2 years. The results were compared to computer simulation of the hydrological characteristic of the lot as if it were paved in asphalt.	Smith, et al., 1981

Management Practice: **FILTRATION BASINS**

DESCRIPTION	LOCATION	WATER-SHED AREA (ACRES	TREAT-MENT VOL. (In.Acre)	FILTRA-TION RATE (In/Hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Filter media consisting of varying layers of gravel, sand	Lab	NA	NA	NA	80-95	30							BOD:70-90 OP: 50	Lab study	Wanielista, et al 1981 cited in City of Austin, 1988
Filter media consisting of alum sludge/sand mixture	Lab	NA	NA	NA	80-90	90							BOD:70-90 OP: 90	Lab study	Wanielista, et al 1981 cited in City of Austin, 1988
Test filter	Lab	NA	NA	NA									OP:75-92	Field study	Harper et al, 1982 cited in City of Austin, 1988
In-line filtration basin, overflows when storage vol. exceeded	Barton Creek Square Mall, Austin, TX	NA	NA	NA	78.3		27.3				33.3	59.5	BOD:75.6 TOC:60.0 TDS:(-12.9) NN:(-111.0) Fe:55.0 FCol:80.7	Excludes storms which overtop the pond	Welborn et al, 1987 cited in City of Austin, 1988
In-line filtration basin, overflows when storage vol. exceeded	Barton Creek Square Mall, Austin TX	NA	NA	NA	58.1	49.9		32.4			38.7	47.4	BOD:75.6 TOC:50.0 TDS:8.9 NN:(-47.3) TKN:49.4 Fe:49.2 FCol:82.9	Includes storms which overtop pond	City of Austin, 1988
Filtration basin - filter media 3" sod, 4" course sand, 8" gravel	Highwood Apartments Austin, TX	3 ac./50% imperv.	1/2" runoff		86			31		45	71	49	TPO4:19 NN:(-5) TKN:48	27 storms monitored between 1985-1987	City of Austin, 1990
Filtration basin - filter media 18" fine sand, 12" coarse sand, 6" gravel	Barton Creek Square Mall, Austin, TX	79 ac./7% imperv.	1/2" runoff		75			44		50	88	82	TPO4:59 NO2+N03: (-13) TKN:64	30 storms monitored between 1985-1987	City of Austin, 1990

Management Practice: **FILTRATION BASINS**

DESCRIPTION	LOCATION	WATER-SHED AREA (ACRES	TREAT-MENT VOL. (In.Acre)	FILTRA-TION RATE (In/Hour)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
					TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Filtration basin - filter media 12" sand, filter fabric, gravel	Jollyville, Austin, TX	9.5 ac/81% imperv.	1/2" runoff		87			32		68	81	80	TPO4:61 NO2+NO3:(-79) TKN:62	20 storms monitored between 1988-1989	City of Austin, 1990
Off-line sedimentation/ filtration basin	Austin, TX	NA	equal or less than 1/2" runoff		80-100	60-80		20-40					OD:40-60 M:60-80 BAC:40-60	Estimates based on above noted studies	City of Austin, 1990
On-line sand/sod filtration basin	Austin, TX	NA	equal or less than 1/2" runoff		80-100	0-20		20-40					OD:20-40 M:40-60 BAC:20-40	Estimates based on above noted studies	City of Austin, 1990
On-line sand filtration basin	Austin, TX	NA	equal or less than 1/2" runoff		60-80	40-60		20-40					OD:20-40 M:60-80 BAC:0-20	Estimates based on above noted studies	City of Austin, 1990

Management Practice: **WATER QUALITY INLET - CATCH BASIN**

DESCRIPTION	LOCATION	WATERSHED AREA (Acres)	TREATMENT VOL. (In/Acre)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
				TSS	TP	SP	TN	NO 3	COD	Pb	Zn	OTHER		
Catch basin cleaned 2 times a year	Toronto Residential	NA								Warm Storm Water: 8; Cold Melt Water: 8; Weighted Total Annual: 8			Monitoring conducted during 1984 & 1985. 100 rains, 50 snowmelts monitored	Pitt & McLean, 1986 cited in Pitt, 1986
Catch basins - cleaned 2 times a year	Boston, Mass.	NA	NA	60-97					10-56			BOC: 54-88	NA	Aronson, 1983 and Field, 1982 cited in Field, 1985

Management Practice: **WATER QUALITY INLET - CATCH BASIN WITH SAND FILTER**														
				REMOVAL EFFICIENCY (%)										
DESCRIPTION	LOCATION	DRAINAGE AREA	LOCATION	TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER	STUDY TYPE	REFERENCE
Catch Basin with sand filter	Austin, Texas	5 ac max		75-86	--	--	31-44	--	45-68	71-88	49-80	--	Monitoring studies by City of Austin, Texas for 3 filtration sites: Highwood, BCSM and Jollyville 1. Removal rates for pollutants have not been widely tested, but they are expected to have removal efficiencies similar to those of filtration basins for highly impervious drainage areas that are less than 5 acres. Results of monitoring studies for filtration basins in Austin, Texas is med.	Shaver, 1991

Management Practice: **WATER QUALITY INLET/OIL-GRIT SEPARATORS**

DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In/Acre)	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
				TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Water quality inlet - 3 chamber	NA	1 ac impervious area max	400 cu ft wet storage per impervious acre	0-20	Insuff. knowledge		Insuff. knowledge		Insuff. knowledge	insuff. knowledge	Insuff. knowledge	BAC insuf. knowledge	Pollutant removal capability of water quality inlets has never been tested in the field, but some general estimates inferred from studies on similar structures such as catch basins and oil/water separators.	Schueler, 1987
Catch basin 3 chamber-cleaned twice a yr.	NA	1 ac max	NA	10-25	5-10		5-10		5-10	10-25	5-10	Nutrients 5-10 Large particles - 50% eff. Finer particles assoc. w/large portion of heavy metals and organic pollutants resuspended.		Pitt, 1985 cited in Schueler, 1987 and City of Austin, 1988

Management Practice: **STREET CLEANING - POLLUTANT REMOVAL IN RUNOFF WATER**

DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	REMOVAL EFFICIENCY (%) IN RUNOFF									STUDY TYPE	REFERENCE
			TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Street cleaning on smooth streets. One or more passes/week One pass/2 weeks One pass/month One pass/2 months One pass/3 months	Toronto residential	NA							Warm Weather Storm Water / Cold Weather Melt Water / Weighted Total Annual 25 0 5 23 0 5 20 0 4 16 0 3 13 0 3			Outfall & source area monitoring conducted during 1984 & 1985. 100 rains, 50 snowmelts monitored	Pitt & McLean, 1986
Street cleaning on rough streets One or more passes/week One pass/2 weeks One pass/month One pass/2 months One pass/3 months	Toronto residential	NA							Warm Weather Storm Water / Cold Weather Melt Water / Weighted Total Annual 15 0 3 12 0 2 10 0 2 7 0 1 6 0 1			Outfall & source area monitoring conducted during 1984 & 1985. 100 rains, 50 snowmelts monitored	Pitt & McLean, 1986 cited in PiH, 1986
Broom street sweeping	National	NA	No significant reduction in urban runoff quality except in areas with accelerated pollutant accumulations (commercial and industrial zones) and in areas with direct surface water runoff to the receiving body.									NURP studies monitored 381 storm events under control conditions and 277 during street sweeping operations	EPA, 1982 cited in City of Austin, 1988
Rotary broom sweeper	Bellevue, Washington	NA	No decrease and possible increase in loadings of solids in runoff from city streets									NURP study	Cited in Puget Sound Water Quality Authority, 1989
Street sweeping	National	NA	Ineffective in 4 out of 5 areas studied									NURP study	Cited in Puget Sound Water Quality Authority, 1989
Street cleaning, 3 passes/week	Castro Valley, Alameda County, CA	NA						Less than 10	35		TS:20 Cu: Less than 10	In-situ, NURP funded	Cited in Pitt, et al, 1981

Management Practice: **STREET CLEANING - POLLUTANT REMOVAL IN RUNOFF WATER**

DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	REMOVAL EFFICIENCY (%) IN RUNOFF									STUDY TYPE	REFERENCE
			TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Street sweeping	National	NA	o Based on statistical testing, no significant reductions in EMCS are realized by street sweeping. o Benefits of street sweeping, if any, are not large (i.e. greater than 50%), and an even larger site data base is required to identify the possible effect. o Street sweeping increasing EMCS generally not shown by the data, though it could occur in isolated, site specific cases.									5 NURP projects, 10 sites, compared end-of-pipe concentrations for adjacent swept and unswept basins	Cited in EPA, 1983

Management Practice: STREET CLEANING - POLLUTANT REMOVAL ON STREET SURFACE														
DESCRIPTION	LOCATION	WATER-SHED AREA (Acres)	% REMOVAL ON STREET SURFACE									STUDY TYPE	REFERENCE
			TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Intensive street cleaning programs	NA	NA									TS: 25-50	NA	Pitt, 1985 cited in City of Austin, 1988
Broom sweeper	Virginia	NA		40		42		31	35	47	BOD: 43 TS: 55	NA	NVPDC, 1979 cited in City of Austin, 1988
Vacuum sweeper	Virginia	NA		74		77		63	76	85	BOD: 77 TS: 93	NA	NVPDC, 1979 cited in City of Austin, 1988
Street sweeping	Wisc.	NA									TS: 10	NURP study in Wisc.	SEWRPC, 1983 cited in City of Austin, 1988
Street cleaning - mechanical and vacuum-assisted mechanical, frequency varied between 2 passes per day and less than 1 pass per week:	San Jose, CA	NA										In-situ Removal efficiencies for COD, TKN, Pb, OP, Zn, Cr, Cu, Cd approx equal to TS	Pitt, 1979 cited in Finnemore, 1982
Asphalt in good condition								30-60	30-60	30-60	TS: 30-60 TKN: 30-60 OP: 30-60		
Asphalt in poor condition								40	40	40	TS: 40 TKN: 40 OP: 40		
Rough oil and screenings surface								5-12	5-12	5-12	TS: 5-12 TKN: 5-12 OP: 5-12		

Management Practice: **STREET CLEANING - POLLUTANT REMOVAL ON STREET SURFACE**

DESCRIPTION	LOCATION	WATERSHED AREA (Acres)	% REMOVAL ON STREET SURFACE									STUDY TYPE	REFERENCE
			TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
Mechanical sweeping	Castro Valley, Alameda County, CA	NA						47-65%	54-63%	52-66%	TS: 53-64 TKN: 50-63 OP: 52-64 Cu: 55-64	RA is most effective in cleaning streets with light loadings; as loadings become heavier, the difference between the two becomes insignificant.	Cited in Pitt, et al, 1981
RA Vacuum	Castro Valley, Alameda County, CA							59-71%	58-74%	60-71%	TS: 61-69 TKN: 60-72 OP: 58-70 Cu: 57-70		
Street sweeping, 4 passes per month (1/week)	Wisconsin: Residential	NA		2%					8-12%		TS: 4	Simulation model studies	Cited in Southeastern Wisconsin Regional Planning, 1991
	Commercial	NA		36%					53%		TS: 47		
	Industrial	NA		27%					37%		TS: 28		
Street cleaning, mechanical sweeper efficiency as a function of sweeping frequency and number of passes			Cleaning Frequency (Days) 60 30 14 7 1	One Pass (%) 41.0 60.5 66.0 75.5 79.4	Two Passes (%) 74.0 87.9 92.1 95.0 96.4	Three Passes (%) 94.8 97.6 98.4 99.0 99.3						NA	Adimi, 1976 cited in Young, et al, 1982

NOTE: The table below provides summary data on the pollutant removal capability of nearly sixty stormwater pond and wetland systems. Each study differs with respect to pond design, number of storms monitored, pollutant removal calculation technique, and monitoring technique, so exact comparisons between studies are not appropriate.

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
DRY ED	1	Lakeridge	VA	28	88.0	0.00	14.0	20.0	(-6.0)	10.0	9.0	(-1.0)		(-10.0)	
	2	London Commons	VA	27	[illegible]	0.22	A: 29.0 B: 74.0	40.0 56.0		25.0 60.0		17.0 31.0	39.0 25.0	24.0 40.0	
	3	[illegible] Stedwick	MD	25	34.0	0.30	70.0	13.0		24.0		27.0	62.0	57.0	TKN: 30.0
	4	Maple Run III	TX	17	28.0	0.50	30.0	18.0		35.0	52.0	22.0	29.0	(-38.0)	TOC: 30.0 Cu: 31.0 BOD: 35.0 NH3: 55.0 FColi: 78.0
	5	Oakhampton	MD		16.8	0.50*	87.0	26.0	(-12.0)		(-10.0)				NH4: 53.5
	6	None given	KS	19	12.3	3.42	3.0	19.0	0.0		20.0	16.0	66.0	65.0	

Note: An asterisk (*) denotes an inferred value

Table taken from Schueler et al, 1992

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET PONDS	7	Seattle	WA	5	0.75		86.7	78.4				64.4	65.1	65.2	Cu: 66.5
	8	Boynton Beach	FL	8			91.0		76.0		87.0				TKN: 58.0
	9	Grace Street	MI	18		VB/VR=.52	32.0	12.0		6.0	(-1.0)		26.0		TKN: 7.0 BOD: 3.0
	10	Pitt-AA	MI	6	4872.0	VB/VR=0.52	32.0	18.0			7.0	23.0	62.0	13.0	TKN: 14.0 BOD: 21.0
	11	Unqua	NY	8		VB/VR=3.07	60.0	45.0					80.0		TOC: 7.0
	12	Waverly Hills	MI	29		VB/VR=7.57	91.0	79.0		62.0	66.0	69.0	95.0	91.0	Cu: 57.0 TKN: 60.0 BOD: 69.0
	13	Lake Ellyn	IL	23		VB/VR=10.70	84.0	34.0					78.0	71.0	Cu: 71.0
	14	Lake Ridge	MN	20	315.0	0.08	A: 90.0 B: 85.0	61.0 37.0	11.0 8.0	41.0 24.0	10.0 17.0		73.0 52.0		TKN: 50.0 TKN: 28.0
	15	West Pond	MN	8	76.0	0.15	65.0	25.0			61.0		8.0-79.0	66.0	TOC: 19.0 TKN: 23.0 Cr: 48.0-76.0 Cd: 12.0-91.0
	16	McCarrons	MN	21	608.0	0.19	91.0	78.0		85.0		90.0	90.0		
	17	McKnight Basin	MN	20	725.0	0.22	A: 85.0 B: 85.0	48.0 34.0	13.0 12.0	30.0 14.0	24.0 11.0		67.0 63.0		TKN: 31.0 TKN: 15.0
	18	Monroe Street	WI		238.0	0.26	90.0	65.0	70.0			70.0	70.0	65.0	Cu: 75.0 FColi: 70.0 Pest: 25-50.0 Hydro: 75-90
	19	Runaway Bay	NC	5	437.0	0.33	54.0	24.0						42.0	TKN: 20.0

Note: An asterisk (*) denotes an inferred value

Table taken from Schueler et al, 1992

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
	20	*Buckland*	CT	7	20.0	0.40	61.0	45.0			22.0		18.0-59.0	51.0	Cd: < 0 TKN: 24.0 TOC: 33.0 Cu: 38.0
	21	Highway Site	FL	13	41.6	0.55	65.0	17.0		21.0		7.0	41.0	37.0	
	22	Woodhollow	TX	14	381.0	0.55	54.0	46.0		39.0	45.0	41.0	76.0	69.0	TKN: 26.0 NH3: 28.0 BOD: 39.0 FColi: 46.0
	23	SR 204	WA	5	1.8	0.60	99.0	91.0				69.1	88.2	87.0	Cu: 90.0
	24	Farm Pond	VA		51.4	1.13	85.0	86.0	73.0	34.0					NH3: (-107.0)
	25	Burke	VA	29	27.1	1.22	(-33.3)	39.0	77.0	32.0		21.0	84.0	38.0	
WET PONDS	26	Westleigh	MD	32	48.0	1.27	81.0	54.0	71.0	37.0		35.0	82.0	26.0	TKN: 27.0
(Cont'd)	27	Mercer	WA	5	7.6	1.72	75.0	67.0				76.9	23.0	38.0	Cu: 51.0
	28	I-4	FL	6	26.3	2.35	54.0	69.0			97.0		41.0-94.0	69.0	TOC: 45.0 TKN: 68.0 Cd: 43.0-51.0 Cu: 66.0-81.0
	29	Timber Creek	FL	9	122.0	3.11*	64.0	60.0	80.0	15.0	80.0				
	30	Maitland	FL	30-40	49.0	3.65			90.0		87.0		95.0	96.0	PP: 11.0 Cu: 77.0 NH3: 82.0
	31	Lakeside	NC	5	65.0	7.16	91.0	23.0						82.0	TKN: 6.0

Note: An asterisk (*) denotes an inferred value

Table taken from Schueler et al, 1992

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET ED	32	Uplands	ONT	5	860.0		82.0	69.0							FColi: 97.0
	33	East Barrhaven	ONT		2139.0	0.12	52.0	47.0							FColi: 56.0
	34	Kennedy-Burnett	ONT	6	395.0	0.62	98.0	79.0		54.0			39.0	21.0	BOD: 36.0 FColi: 99.0
STORMWATER WETLANDS	35	EWA3	IL				72.0	59.0			70.0				Fe: 48.0
	36	EWA4	IL				76.0	55.0			42.0				Fe: 43.0
	37	EWA5	IL				89.0	69.0			70.0				Fe: 50.0
	38	EWA6	IL				98.0	97.0			95.0				Fe: 92.0
	39	B31	WA	13	461.7	0.01	14 0	(-2.0)			4 0				
	40	PC12	WA	13	214.8	0.03	56.0	(-2.0)			20.0				
	41	McCarrons	MN	21	608.0	0.31	87.0	36.0		24.0		79.0	68.0		
	42	Queen Anne's	MD			0.50*	65 0	39.0	44.0	23.0	55 0				NH4: 55 0 ON: (- 5.0) PP: 7.2
	43	Swift Run	MI	5	1207.0	0.60	85.0	3.0	29.0		80.0	2.0	82.0		BOD: 4.0
	44	Tampa Office Pond	FL	3 - 8	6.3	0.61	64.0	55.0	65.0					34.0	ON: (-3.7)
	45	Highway Site	FL	13	41.6	0.81	66.0	19.0		30.0		18.0	75.0	50.0	
	46	Palm Beach PGA	FL		2340.0	2.00*	50.0	62.0			33.0				NH3: 17.0 BOD: 35.0 TOC: 10.0 TKN: 16.0
ED WETLANDS	47	Benjamin Franklin	VA		40.0	0.08	62.0	14.9	23.6		60.0			(-73.5)	Cd: (-79.8) NH3: 0.0 TKN: 4.4

Note: An asterisk (*) denotes an inferred value

Table taken from Schueler et al, 1992

Table 1. LITERATURE RESEARCHED TO INVESTIGATE PERFORMANCE CHARACTERISTICS OF WETLANDS

Study		Location	Name / I. D.	Detention Pond /Wetland	Constructed /Natural	Wetland Classificaton
Martin and Smoot	1986	Orange County, Florida	Orange County Treatment System	detention pond wetland	constructed	hardwood cypress dome
Harper et al.	1986	Florida	Hidden Lake	wetland	natural	hardwood swampland
Reddy et al.	1982	Orange County, Florida	Lake Apopka	wetland	constructed	cattail marsh
Blackburn et al.	1986	Palm Beach, Florida	Palm Beach PGA Treatment System	wetland	constructed and natural	southern marshland
Esry and Cairns	1988	Tallahassee, Florida	Jackson Lake	detention pond wetland	constructed	southern marshland
Brown, R.	1985	Twin Cities Metro Area, Minnesota	Twin Cities Metro	wetlands	natural and constructed	northern peatland
Wotzka and Oberts	1988	Roseville, Minnesota	McCarrons Treatment System	detention pond wetland	constructed	cattail marsh
Hickok et al.	1977	Minnesota	Wayzata	wetland	natural	northern peatland
Barten	1987	Waseca, Minnesota	Clear Lake	wetland	constructed	cattail marsh

Taken from Woodward-Clyde, 1991

Table I. LITERATURE RESEARCHED TO INVESTIGATE PERFORMANCE CHARACTERISTICS OF WETLANDS

Study		Location	Name / I. D.	Detention Pond /Wetland	Constructed /Natural	Wetland Classificaton
Meiorin	1986	Fremont, California	DUST Marsh	wetland	constructed	brackish marsh
Morris et al.	1981	Tahoe Basin, California	Tahoe Basin Meadowland	wetland	constructed ?	high elevation riverine
Scherger and Davis	1982	Ann Arbor, Michigan	Pittsfield-Ann Arbor Swift Run	detention pond wetland	constructed and natural	northern peatland
ABAG	1979	Palo Alto, California	Palo Alto Marsh	wetland	natural	brackish marsh
Jolly	1990	St. Agatha, Maine	Long Lake Wetland-Pond Treatment System	detention pond wetland	constructed	cattail marsh
Oberts et al.	1989	Ramsey-Washington Metro Area, Minnesota	Tanners Lake, McKnight Lake, Lake Ridge, and Carver Ravine	detention ponds wetlands	constructed	cattail marsh
Reinelt et al.	1990	King County, Washington	B3I and PC12	wetlands	natural	palustrine
Rushton and Dye	1990	Tampa, Florida	Tampa Office Pond	wetland	constructed	cattail marsh
Hey and Barrett	1991	Wadsworth, Illinois	Des Plaines River Wetland Demonstration Project	wetland	constructed	freshwater riverine

Taken from Woodward-Clyde, 1991

Table 2. AVERAGE REMOVAL EFFICIENCIES FOR TOTAL SUSPENDED SOLIDS AND NUTRIENTS IN WETLANDS REPORTED IN THE LITERATURE

			POLLUTANT REMOVAL EFFICIENCY (PERCENT)											
Study	System Name	System Type	TSS	VSS	TN	TKN	Org. N	NH3	NO3	TP	Ortho-P	Dis. P	COD	BOD
Martin and Smoot	Orange County	detention pond *	65	60	19		17	60	-17	33	57	76	7	
1986	Treatment System	wetland *	66	60	21		23	54	40	17	2	-30	18	
		entire system	89	85	36		39	61	9	43	28	21	17	
Harper et al. 1986	Hidden Lake	wetland	83		-1.6		-24	62	80	7	-109			81
Reddy et al.	Lake Apopka	reservoirs				4.8		57.5	68.1	60.9		75.1		
1986		flooded fields				-7.6		51.9	64.2	7.3		16.7		
Blackburn et al. 1986	Palm Beach PGA Treatment System	system	50			16		17	33	62				35
Eary and Cairns 1988	Jackson Lake	system	96		76			37	70	90		78		
Brown	Fish Lake	wetland/pond	95	78	-20		36	0		37		28		
1985	Lake Elmo	wetland	88	80	38		-36	50		27		25		
	Lake Riley	wetland	-20	20	20		7	25		-43		-30		
	Spring Lake	wetland		-20	-14		11	-86		-7		-10		
Wotzka and Obert	McCarrons Wetland	detention pond *	91	95	85	88			60	78		57	90	
1988	Treatment System	wetland *	87	87	24	26			22	36		25	79	
		system	94	94	83	85			63	78		53	93	
Hickok et al. 1977	Wayzata Wetland	wetland	94					-44		78				
Barten 1987	Clear Lake	wetland	76			25		55		54	52	40		
Meiorin	DUST Marsh													
1986	Basin A	wetland *	63			22		-8	32	46	65			-25
	Basin B	wetland *	40			-27		-5	2	-4	28			-46
	Basin C	wetland *	51			-1		18	12	36	37			-18
	System	wetland	76			-1		16	29	58	68			-57
Morris et al.	Angora Creek	wetland	54			-20		20	50	5				
1981	Tallac Lagoon	wetland	36			-88		33	35	-120				
Scherger and Davis	Pittsfield-Ann Arbor	detention pond *	39			14				23				
1982	Swift Run	wetland	76			20				49				
ABAG 1979	Palo Alto Marsh	wetland	87	85	37					-6				54
Jolly 1990	Long Lake Wetland-Pond Treatment System	entire system	95	94						92				
Oberts et al.	Tanners Lake	detention pond *	63	50	5	7			1	7	20	-14		
1989	McKnight Lake	detention ponds *	85	57	14	15			11	34	34	12		
	Lake Ridge	wetland	85	67	24	28			17	37	-5	8		
	Carver Ravine	wetland-pond system	20	1	-6	-10			9	1	-3	1		
Reinelt et al.	B31	wetland	14						4	-2				
1990	PC12	wetland	56						20	-2				
Rushton and Dye 1990	Tampa Office Pond	wetland	64				-3.7			55	65			
Hey and Barrett	Des Plaines River Wetland													
1991	EWA 3	wetland	72						70	59				
	EWA 4	wetland	76						42	55				
	EWA 5	wetland	89						70	69				
	EWA 6	wetland	98						95	97				
Median pollutant efficiency for wetland systems (without *):			76	79	24	5	7	33	46	46	28	23	55	45

Negative ("-") removal efficiencies indicate net export in pollutant loads.

Taken from Woodward-Clyde, 1991

Table 3. AVERAGE REMOVAL EFFICIENCIES FOR METALS AND OIL AND GREASE IN WETLANDS REPORTED IN THE LITERATURE

			Lead		Zinc		Copper		Cadmium		Nickel		Chromium		Oil and
Study	System Name	System Type	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	Grease
Martin and Smoot 1986	Orange County Treatment System	detention pond *	39	29	15	-17									
		wetland *	73	54	56	75									
		entire system	83	70	70	65									
Harper et al. 1986	Hidden Lake	wetland	55	56	41	57	40	29	71	79	70	70	73	75	
Reddy et al. 1986	Lake Apopka	reservoirs													
		flooded fields													
Blackburn et al. 1986	Palm Beach PGA Treatment System	system													
Esry and Cairns 1988	Jackson Lake	system													
Brown 1985	Fish Lake	wetland/pond													
	Lake Elmo	wetland													
	Lake Riley	wetland													
	Spring Lake	wetland													
Wotzka and Obert 1988	McCarrons Wetland Treatment System	detention pond *	85												
		wetland *	68												
		system	90												
Hickok et al. 1977	Wayzata Wetland	wetland	94		82		80		67						
Barten 1987	Clear Lake	wetland													
Meiorin 1986	DUST Marsh														
	Basin A	wetland *	30		42		-20				36		55		32
	Basin B	wetland *	27		24		-60				-12		47		-57
	Basin C	wetland *	83		-29		17				11		13		13
	System	wetland	88		42		-19				26		66		-25
Morris et al. 1981	Angora Creek	wetland													
	Tallac Lagoon	wetland													
Scherger and Davis 1982	Pittsfield-Ann Arbor	detention pond *	61												0
	Swift Run	wetland	83												0
ABAG 1979	Palo Alto Marsh	wetland													
Jolly 1990	Long Lake Wetland-Pond Treatment System	entire system													
Oberts et al. 1989	Tanners Lake	detention pond *	59												
	McKnight Lake	detention ponds *	63												
	Lake Ridge	wetland	52												
	Carver Ravine	wetland-pond system	6												
Reinelt et al. 1990	B3I	wetland													
	PC12	wetland													
Rushton and Dye 1990	Tampa Office Pond	wetland			34										
Hey and Barrett 1991	Des Plaines River Wetland														
	EWA 3	wetland													
	EWA 4	wetland													
	EWA 5	wetland													
	EWA 6	wetland													
Median pollutant efficiency for wetland systems (without *):			83	63	42	61	40	29	69	79	48	70	70	75	-13

Negative ("-") removal efficiencies indicate net export in pollutant loads.

Taken from Woodward-Clyde, 1991

Table 4. WETLAND GEOGRAPHIC AND HYDRAULIC CHARACTERISTICS

Study	System Name	Watershed Land Use	% Land Use	System Type	Wetland Size (acres)	Watershed Size (acres)	Wetland/ Watershed Ratio	Average Flows (cfs)	Basin Volume (acre-ft)	Detention Time (hours)	Depth (ft)	Inlet Condition	Comments
Martin and Smoot	Orange County	residential	33	detention pond	0.2	41.6	0.5%	2.5	1.2-1.9	7.5	8 - 11	discrete	• Short circuiting was observed during several storms.
1986	Treatment System	highway	27	wetland	0.78		1.9%		0.5-2.8	8	0-5	discrete	
		forest	40	system	0.98		2.4%						
Harper et al.	Hidden Lake	residential	NA	wetland	2.5	55.2	4.5%	0.22	NA	NA	NA	diffuse	• The wetland is not a basin, but similar to a grassy swale.
1986													
Reddy et al.	Lake Apopka	agriculture	100	reservoirs	0.9	NA	NA	0.56	2.6	9.4 days	3.3	diffuse	• Design configuration suggests little short circuiting occurred.
1982				flooded fields	0.9			0.23	0.6	4.8 days	0.7		
Blackburn et al.	Palm Beach PGA	residential	NA	wetland	89	2350	3.8%	NA	NA	NA	NA	diffuse	• Design configuration suggests little short circuiting occurred.
1986	Treatment System	golf course		wetland	296		12.6%						• Generally sheet flow exists within the artificial wetland.
Erry and Cairns	Jackson Lake	urban	NA	detention pond	20	2230	0.9%	NA	150	NA	7.5	diffuse	• Design configuration suggests little short circuiting occurred.
1988				wetland	9		0.4%		13.5		1.5		
Brown	Fish Lake	residential	30	wetland	16	700	2.3%	0.001-0.01	64	NA	4	discrete	• The major influent to these natural wetlands is discrete channelized flow.
1985		commercial	5										
		agriculture	12										
		open	53										• The schematic suggests large areas of dead storage.
	Lake Elmo	residential	12	wetland	225	2060	10.9%	0.001-0.65	900	NA	4	discrete	• Short circuiting was not discussed by the author.
		commercial	1										
		agriculture	34										
		open	53										
	Lake Riley	residential	13	wetland	77	2475	3.1%	0.004-1.35	231	NA	3	discrete	
		commercial	2										
		agriculture	30										
		open	55										
	Spring Lake	residential	5	wetland	64	5570	1.1%	0.008-4	256	NA	4	discrete	
		commercial	1										
		agriculture	57										
		open	37										
Wotzka and Obert	McCarrons Wetland	urban	NA	detention pond	2.47	600	0.4%	0.05-.2	2.3-9.7	24 days	2.5	diffuse	• Three discrete inlets help to minimize short circuiting and dissipate surface water energy.
1988	Treatment System			wetland	6.2		1.0%					diffuse	
				system	8.67		1.4%						
Hickok et al.	Wayzata Wetland	residential	NA	wetland	7.6	65.1	11.7%	0.08	NA	NA	NA	discrete	• Design configuration suggests minimal short circuiting existed regardless of a single discrete inlet.
1977		commercial											
Barten	Clear Lake	urban	NA	wetland	52.9	1070	4.9%	1.5	10	3-5 days	0.5	diffuse	
1987													
Meiorin	DUST Marsh	urban	93	wetland A	5	2960	0.2%	10-250	150	4-40 days	4.7	diffuse	• Design configuration suggests little short circuiting occurred due to long and narrow wetland basins.
1986		agriculture	7	wetland B	6		0.2%						
				wetland C	21		0.7%						
				wetland (system)	32		1.1%						
Morris et al.	Angora Creek			wetland	NA	2816	NA	8.46	NA	NA	NA	diffuse	• Flow occurs as channelized flow until the storm volume is large enough to force sheet flow through the meadowlands.
1981	Tallac Lagoon			wetland	NA	2781	NA	8.68	NA	NA	NA	diffuse	
Scherger and Davis	Pittsfield-Ann Arbor	residential	45	detention pond	25.3	4872	0.5%	0-2916	21-176	4-105	0-6	discrete	• The schematic suggests large areas of dead storage exist.
1982	Swift Run	commercial	19	wetland	25.5	1207	2.1%	0-166	15-60	12 - 82	0-3	discrete	
		agriculture	13										
		open	23										

Taken from Woodward-Clyde, 1991

Table 4. WETLAND GEOGRAPHIC AND HYDRAULIC CHARACTERISTICS (concluded)

Study	System Name	Watershed Land Use	% Land Use	System Type	Wetland Size (acres)	Watershed Size (acres)	Wetland/ Watershed Ratio	Average Flows (cfs)	Basin Volume (acre-ft)	Detention Time (hours)	Depth (ft)	Inlet Condition	Comments
ABAG 1979	Palo Alto Marsh	residential	62	wetland	613	17600	3.5%	150-320	400-750	30	1 - 6	discrete	• Water level and volume are controlled by the tidal cycle.
		commercial	12										• Channelized flow exist until the tide increases causing the surrounding marsh to become inundated.
		open	26										
Jolly 1990	Long Lake Wetland-Pond Treatment System	agriculture	100	wetland-pond	1.5	18	8.3%	0.01	1.5	NA	0.5-8	diffuse	• Entire system consists of a sedimentation basin, grass filter strip, constructed wetland, and deep pond.
Oberts et al. 1989	Tanners Lake	residential	NA	pond	0.07	1134	negligible	NA	0.1	NA	3.0	discrete	• Monitoring occurred during a dry period.
	McKnight Lake	residential	NA	pond	5.53	5217	0.1%	NA	13.2	NA	4.9	discrete	
	Lake Ridge	residential	NA	wetland	0.94	531	0.2%	NA	2.0	NA	4.8	discrete	
	Carver Ravine	residential	NA	wetland-pond	0.37	170	0.2%	NA	1.0	NA	2.0	discrete	
Reineh et al. 1990	B31	urbanized	NA	wetland	4.9	461.7	1.1%	1.5	0.03-0.43	3.3	NA	discrete	• Storm flows reduce detention times.
	PC12	rural	NA	wetland	3.7	214.8	1.7%	0.7	0.05-0.60	2.0	NA	discrete	• Channelization reduced effective area in wetland.
Rushton and Dye 1990	Tampa Office Pond	commercial	100	wetland	0.35	6.3	5.6%	NA	0.32	NA	0-1.5	discrete	• Overflow from adjacent wetlands occurred during extremely high water; leak and breach problems occurred during study.
Hey and Barrett 1991	Des Plaines River Wetland Demonstration Project	NA	NA	EWA 3	5.6	-	-	5	NA	NA	1	discrete	• Water is pumped to the system from the river (drainage area of 210 square miles) for 20 hours per week.
		NA	NA	EWA 4	5.6	-	-	0.6	NA	NA	1	discrete	
		NA	NA	EWA 5	4.5	-	-	4	NA	NA	1	discrete	
		NA	NA	EWA 6	8.3	-	-	1	NA	NA	1	discrete	

NA = Not available

Taken from Woodward-Clyde, 1991

Table 5. SAMPLING CHARACTERISTICS FROM THE WETLANDS REVIEWED

Study	Location	Time of Study	Length of Study	Type of Sample	Number of Storms Monitored	Method of Computing Efficiencies
Martin and Smoot 1986	Orange County, Florida	1982-1984	2 years	7 multi grab 6 composite	13	ROL
Harper et al. 1986	Florida	1984-1985	1 year	composite	18	ER
Reddy et al. 1982	Orange County, Florida	1977-1979	2 years	single grab	~150	MC
Blackburn et al. 1986	Palm Beach, Florida	1985	1 year	single grab	36	MC
Esry and Cairns 1988	Tallahassee, Florida	1985	NA	NA	1	NA
Brown 1985	Twin Cities Metro Area, Minnesota	1982	1 year	composite	5 - 7	SOL
Wotzka and Oberts 1988	Roseville, Minnesota	1984-1988	2 years	composite	25	ROL
Hickok et al. 1977	Minnesota	1974-1975	10 months	NA	NA	SOL
Barten 1987	Waseca, Minnesota	1982-1985	3 years	composite	27	ER
Meiorin 1986	Coyote Hills, Fremont, Ca.	1984-1986	2 years	composite	11	SOL
Morris et al. 1981	Tahoe Basin, California	1977-1978	1 year	single grab	~75	MC
Scherger and Davis 1982	Ann Arbor, Michigan	1979-1980	8 months	composite	7	SOL
ABAG 1979	Palo Alto, California	1979	3 months	composite	8	ER
Jolly 1990	St. Agatha, Maine	1989	5 months	composite	11	SOL
Oberts et al. 1989	Ramsey-Washington Metro Area, Minnesota	1987-1989	2 years	composite	7-22	SOL
Reinelt et al. 1990	King County, Washington	1988-1990	2 years	composite	13	SOL
Rushton and Dye 1990	Tampa, Florida	1989-1990	12 months	composite	3-8	ER
Hey and Barrett 1991	Wadsworth, Illinois	1990	8 months	discrete	continuous	SOL

Table Notes:
ER = Event mean concentration
SOL = Sum of event loads
ROL = Regression of event loads
MC = Mean concentration
NA = Not available

Taken from Woodward-Clyde, 1991

NOTATION

BAC: Bacteria
BOD: Biological Oxygen Demand
Cd: Cadmium
COD: Chemical Oxygen Demand
Cr: Chromium
Cu: Copper
FCol: Fecal Coli
Fe: Iron
N: Nutrients
NH3: Ammonia
NN: Nitrate/Nitrite
NO3: Nitrate
OD: Oxygen Demand
ON: Organic Nitrogen
OP: Ortho-Phosphorus
Pb: Lead
SP: Soluble Phosphorus
TDS: Total Dissolved solids
TKN: Total Kgeldahl Nitrogen
TM: Trace Metals
TN: Total Nitrogen
TOC: Total Organic Carbon
TP: Total Phosphorus
TS: Total Solids
TSS: Total Suspended Solids
Zn: Zinc

NA: NOT AVAILABLE

COMPUTER RUNS TO DETERMINE REMOVAL EFFICIENCY OF INFILTRATION BASINS AND TRENCHES IN VARIOUS REGIONS

PACIFIC NORTHWEST

	Mean	Coef. of Variation
Volume	0.5	1.09
Intensity	0.035	0.73
Duration	15.9	0.8
Interval	123	1.5

Area= 1 ac

Rv= 0.5

Volume= 90% ave runoff (0.23 in. runoff) 817 cf (1 ac * 0.50 * 0.50 in * 90%)

QR	VR
63.525	907.5

*** Perc. Rate (in/hr)	*** Height (ft)	Surf. Area (sq. ft.)	QT	QT/QR	VB	VB/VR	E	*Fig 4* VE/VR	*Fig 1* % FLOW	*Fig 3 % VOL	% REMOVAL
8.27	2	408.4	281.4	4.43	816.8	0.9	38.1	0.9	100	58.0	100.0
2.41	3.2	255.2	51.3	0.81	816.8	0.9	6.9	0.9	66	58.0	85.7
2.41	8	102.1	20.5	0.32	816.8	0.9	2.8	0.9	31	58.0	71.0
1	1.2	680.6	56.7	0.89	816.8	0.9	7.7	0.9	68	58.0	86.6
1	2	408.4	34.0	0.54	816.8	0.9	4.6	0.9	48	58.0	78.2
1	5	163.4	13.6	0.21	816.8	0.9	1.8	0.8	19	55.0	63.6
0.5	3	272.3	11.3	0.18	816.8	0.9	1.5	0.8	16	55.0	62.2
0.27	8	102.1	2.3	0.04	816.8	0.9	0.3	0.3	0	23.0	23.0

Computed from Woodward-Clyde, 1986

PACIFIC SOUTH

	Mean	Coef. of Variation
Volume	0.54	0.98
Intensity	0.054	0.76
Duration	11.6	0.78
Interval	476	2.09

Area= 1 ac
Rv= 0.5
Volume= 90% ave runoff (0.24 in. runoff) 871 cf (1 ac * 0.50 * 0.54 in * 90%)

QR	VR
98.01	980.1

*** Perc. Rate (in/hr)	*** Height (ft)	Surf. Area (sq. ft.)	QT	QT/QR	VB	VB/VR	E	*Fig 4* VE/VR	*Fig 1* % FLOW	*Fig 3 % VOL	% REMOVAL
8.27	2	435.6	300.2	3.06	871.2	0.9	145.8	0.9	100	58.0	100.0
2.41	3.2	272.3	54.7	0.56	871.2	0.9	26.6	0.9	50	58.0	79.0
2.41	8	108.9	21.9	0.22	871.2	0.9	10.6	0.9	21	58.0	66.8
1	1.2	726.0	60.5	0.62	871.2	0.9	29.4	0.9	54	58.0	80.7
1	2	435.6	36.3	0.37	871.2	0.9	17.6	0.9	36	58.0	73.1
1	5	174.2	14.5	0.15	871.2	0.9	7.1	0.9	15	58	64.3
0.5	3	290.4	12.1	0.12	871.2	0.9	5.9	0.9	12	58	63.0
0.27	8	108.9	2.5	0.03	871.2	0.9	1.2	0.8	0	50.0	50.0

Computed from Woodward-Clyde, 1986

EAST GULF

	Mean	Coef. of Variation
Volume	0.8	1.19
Intensity	0.178	1.03
Duration	6.4	1.05
Interval	130	1.25

Area= 1 ac
Rv= 0.5
Volume= 90% ave runoff 1307 cf
(0.36 in. runoff) (1 ac * 0.50 * 0.80 in * 90%)

QR	VR
323.07	1452

*** Perc. Rate (in/hr)	*** Height (ft)	Surf. Area (sq. ft.)	QT	QT/QR	VB	VB/VR	E	*Fig 4* VE/VR	*Fig 1* % FLOW	*Fig 3 % VOL	% REMOVAL
8.27	2	653.4	450.3	1.39	1306.8	0.9	40.3	0.9	72	55.0	87.4
2.41	3.2	408.4	82.0	0.25	1306.8	0.9	7.3	0.9	23	55.0	65.4
2.41	8	163.4	32.8	0.10	1306.8	0.9	2.9	0.9	8	55.0	58.6
1	1.2	1089.0	90.8	0.28	1306.8	0.9	8.1	0.9	24	55.0	65.8
1	2	653.4	54.5	0.17	1306.8	0.9	4.9	0.9	18	55.0	63.1
1	5	261.4	21.8	0.07	1306.8	0.9	2.0	0.8	0	50.0	50.0
0.5	3	435.6	18.2	0.06	1306.8	0.9	1.6	0.8	0	50.0	50.0
0.27	8	163.4	3.7	0.01	1306.8	0.9	0.3	0.2	0	18.0	18.0

*Computed from Woodward-Clyde, 1986

MID-ALTLANTIC

	Mean	Coef. of Variation
Volume	0.64	1.01
Intensity	0.092	1.2
Duration	10.1	0.84
Interval	143	0.97

Area= 1 ac

Rv= 0.5

Volume= 90% ave runoff 1053 cf

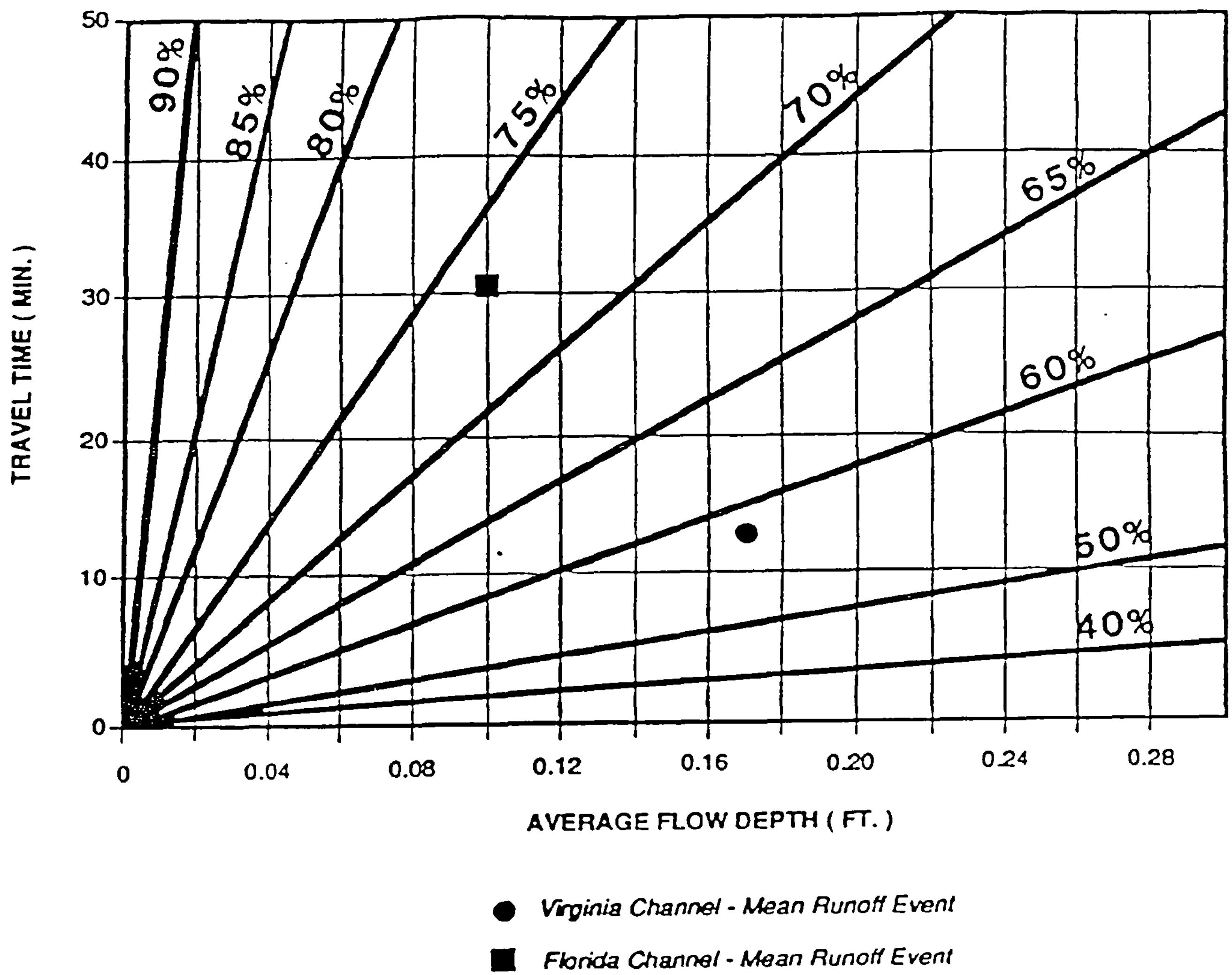
(0.29 in. runoff) (1 ac * 0.50 * 0.64 in * 90%)

QR	VR
166.98	1161.6

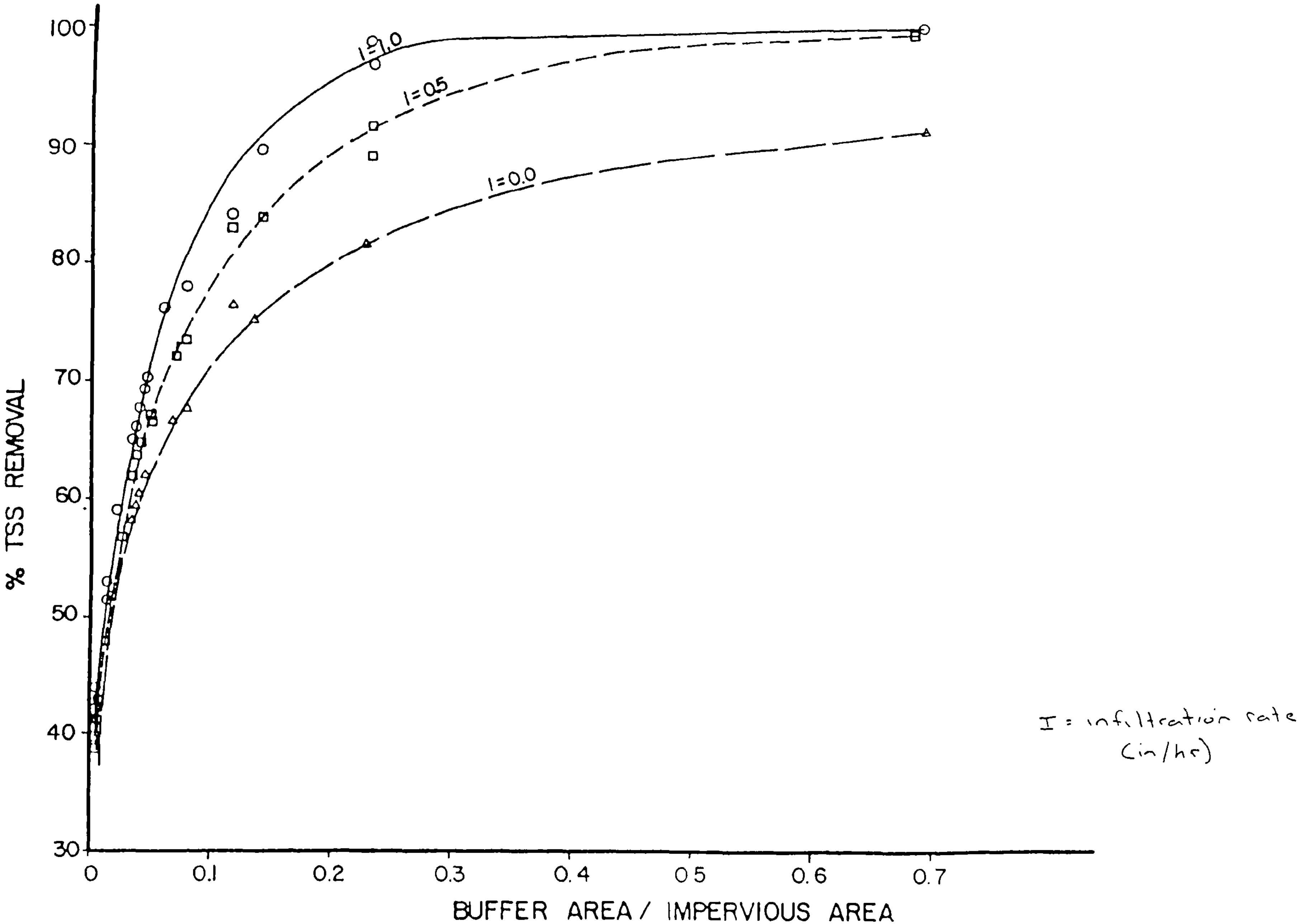
*** Perc. Rate (in/hr)	*** Height (ft)	Surf. Area (sq. ft.)	QT	QT/QR	VB	VB/VR	E	*Fig 4* VE/VR	*Fig 1* % FLOW	*Fig 3 % VOL	% REMOVAL
8.27	2	526.4	362.7	2.17	1052.7	0.9	44.7	0.9	81	58.0	92.0
8.27	5	210.5	145.1	0.87	1052.7	0.9	17.9	0.9	51	58.0	79.4
8.27	8	131.6	90.7	0.54	1052.7	0.9	11.2	0.9	35	58.0	72.7
2.41	3.2	329.0	66.1	0.40	1052.7	0.9	8.1	0.9	30	58.0	70.6
2.41	8	131.6	26.4	0.16	1052.7	0.9	3.3	0.9	13	58.0	63.5
1	1.2	877.3	73.1	0.44	1052.7	0.9	9.0	0.9	33	58.0	71.9
1	2	526.4	43.9	0.26	1052.7	0.9	5.4	0.9	19	58.0	66.0
1	5	210.5	17.5	0.11	1052.7	0.9	2.2	0.9	7	58.0	60.9
0.5	3	350.9	14.6	0.09	1052.7	0.9	1.8	0.9	0	58.0	58.0
0.27	2	526.4	11.8	0.07	1052.7	0.9	1.5	0.8	0	53.0	53.0
0.27	5	210.5	4.7	0.03	1052.7	0.9	0.6	0.5	0	39.0	39.0
0.27	8	131.6	3.0	0.02	1052.7	0.9	0.4	0.3	0	25.0	25.0

Computed from Woodward-Clyde, 1986

VEGETATIVE FILTER STRIP REMOVAL EFFICIENCY CHART



Taken from Hartigan et al, 1989



Taken from IEP, Inc. 1991

APPENDIX C

COST DATA

BMP CONSTRUCTION COST ESTIMATES

(Cost include construction costs only, exclude land, engineering, etc.)

INFILTRATION BASIN

INFILTRATION BASIN– Washington, D.C. (based on equation from regression analysis from bids for for 53 ponds and taking out 50% of outlet cost; Wiegand et al, 1986

$C=3.05*V^{0.75}$

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
10,000	3,146	0.31	3–5%
20,000	5,290	0.26	3–5%
30,000	7,170	0.24	3–5%
40,000	8,897	0.22	3–5%
50,000	10,518	0.21	3–5%
60,000	12,059	0.20	3–5%
70,000	13,537	0.19	3–5%
80,000	14,963	0.19	3–5%
90,000	16,345	0.18	3–5%
100,000	17,689	0.18	3–5%

Note: Cost estimates from Schueler et al, 1985 were not used since Wiegand et al, 1986 compares and updates

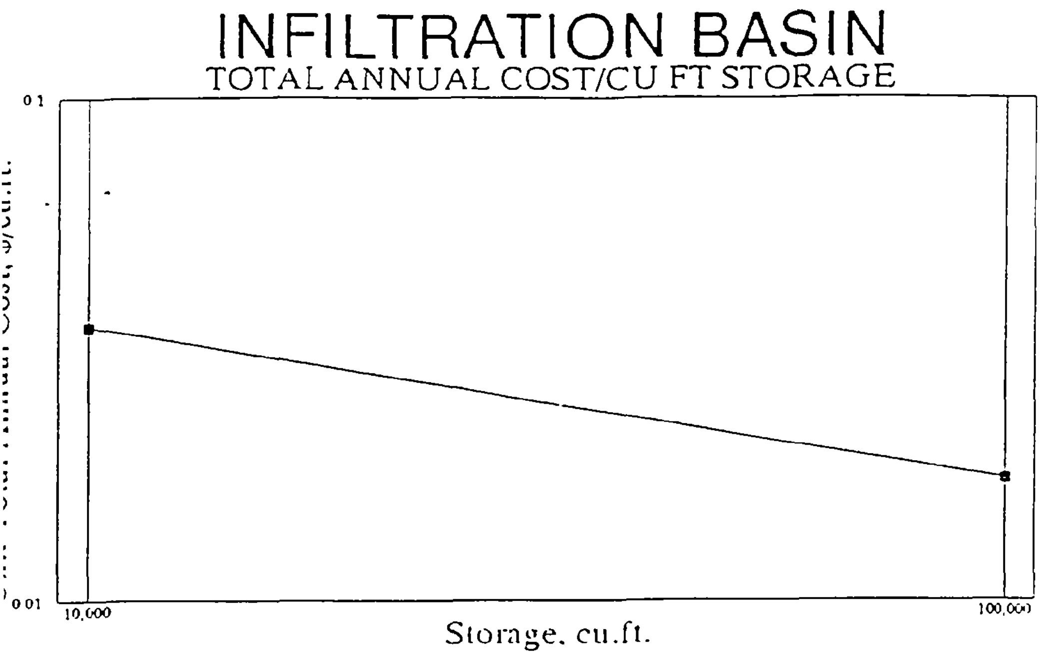
INFILTRATION BASIN– Oconomowoc, Wisconsin (estimated for 3 foot deep infiltration basin)

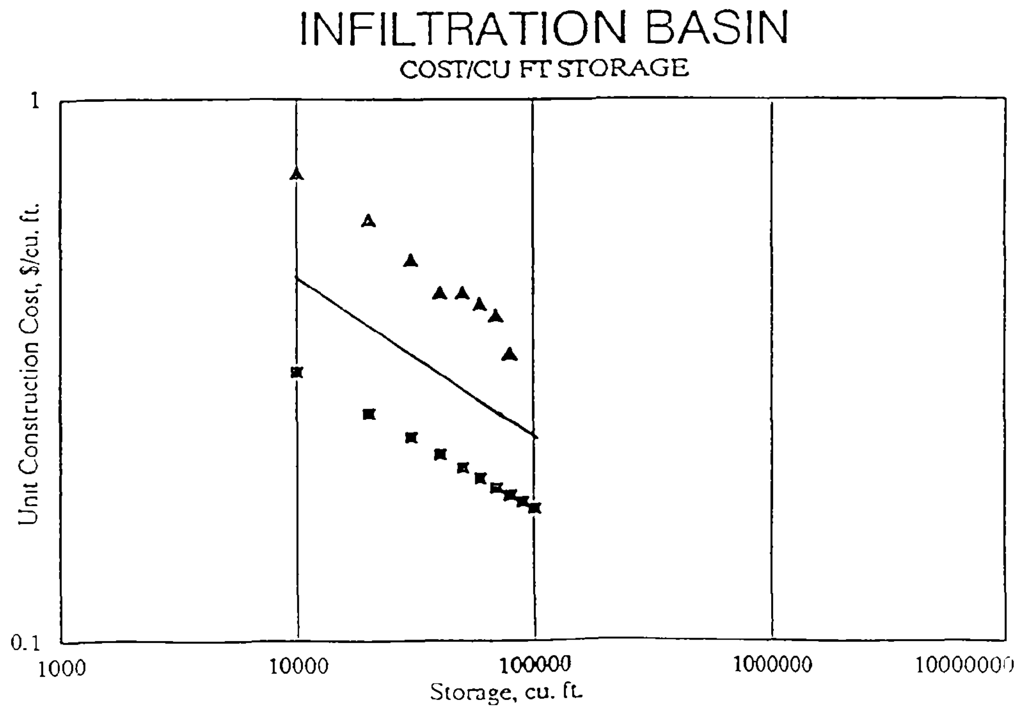
Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
NA	NA	1.18	13%

INFILTRATION BASINS– Southeastern Wisconsin (estimated from graphs caluculated from unit costs); SWRPC, 1991

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
30,000	22,000	0.73	5%
50,000	30,000	0.60	4%
75,000	38,000	0.51	3%
100,000	44,000	0.44	3%
250,000	110,000	0.44	3%
500,000	210,000	0.42	3%
750,000	300,000	0.40	3%
1,000,000	340,000	0.34	3%

CHART 1. UNIT CONSTRUCTION COST AND TOTAL ANNUAL COST OF INFILTRATION BASIN





INFILTRATIONTRENCH

INFILTRATION TRENCH – Washington, D.C. (based on equation from regression analysis from bids for 7 trenches); Wiegand, et.al., 1986
C=26.55*V^0.63 V= volume of void space

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
300	996	3.32	NA
500	1,373	2.75	NA
750	1,773	2.36	NA
1,000	2,125	2.13	NA
2,000	3,289	1.64	NA
3,000	4,247	1.42	NA
4,000	5,090	1.27	NA
5,000	5,859	1.17	NA
6,000	6,572	1.10	NA
7,000	7,242	1.03	NA
8,000	7,878	0.98	NA
9,000	8,485	0.94	NA
10,000	9,067	0.91	NA

SURFACE INFILTRATION TRENCH– Washington, D.C.; Macal, et.al., 1987

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
NA	NA	NA	5–10%

UNDERGROUND INFILTRATION TRENCH – Washington, D.C.; Macal, et.al., 1987

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
NA	NA	NA	10–15%

INFILTRATION TRENCH – Wisconsin (estimated from graphs calculated from unit costs, assumed storage volume equals 40% total volume); SE Wisc. Reg. Planning Comm., 1991

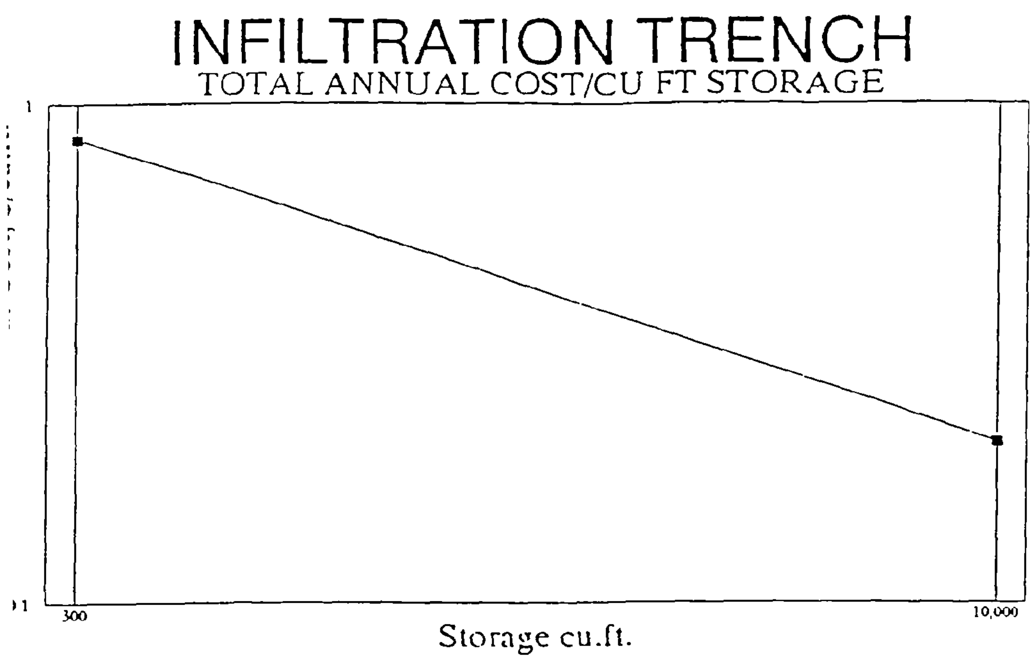
Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)	Comments
198	1,815	9.17	7%	5'x3'x33'
304	1,805	5.94	5%	5'x8'x19'
300	2,750	9.17	7%	5'x3'x50
2004	12,525	6.25	7%	10'x3'x167'
2016	9,450	4.69	5%	10'x8'x63'
3996	21,756	5.44	6%	15'x3'x222'
3984	16,600	4.17	6%	15'x8'x83
9600	40,000	4.17	6%	15'x8'x200'

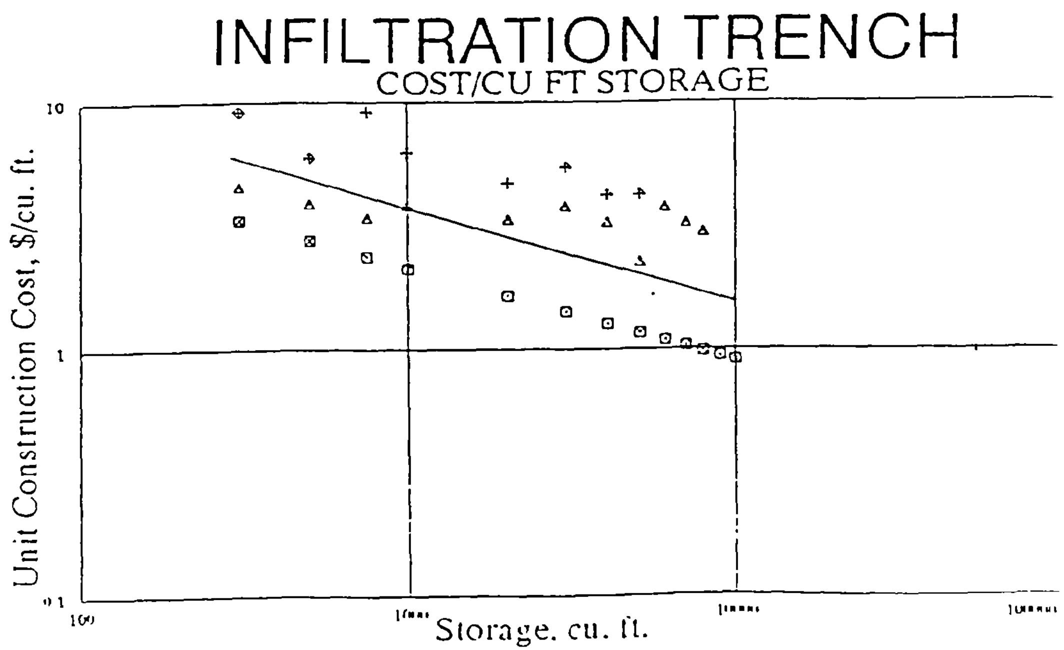
INFILTRATION TRENCH – (based on equation); Kuo, et.al., 1988

cost= 1.28*(0.68*(w*/*(d+1))+0.28*((w*l)+(w*d)+(l*w))+2.5*(d+1)+0.04*((20+w)+(40+l))

Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)	Comments
80	364	4.55	NA	5'x2'x20'
198	768	3.88	NA	5'x3'x33'
234	799	3.41	NA	5'x8'x13'
300	1,145	3.82	NA	5'x3'x50'
304	1,013	3.33	NA	5'x8'x19'
402	1,521	3.78	NA	5'x3'x67'
400	1,306	3.27	NA	5'x8'x25'
3,004	6,806	2.27	NA	10'x3'x167'
750	2,805	3.74	NA	5'x3'x125'
4,000	12,844	3.21	NA	10'x4'x250'
4,000	11,879	2.97	NA	10'x8'x125'

CHART 2. UNIT CONSTRUCTION COST AND TOTAL ANNUAL COST OF INFILTRATION TRENCH





VEGETATIVE BUFFER STRIP

GRASS BUFFER STRIP– Washington, D.C.; Schueler, 1987

Establishmen Method	Area (acres)	1988 Cost/ac. ($/ac.)	Annual Maint. Cost (% capital cost)
Hydroseedin(	1–2	2,024	NA
Hydroseedin(	2–5	1,793	NA
Hydroseedin(	5+	1,486	NA
Conventional	1–2	1,845	NA
Conventional	2–5	1,691	NA
Conventional	5+	1,486	NA
Conventional blanket or net	1–2	8,686	NA
Sodding	1–2	11,171	NA

FOREST BUFFER STRIP– Washington, D.C.; Schueler, 1987

	1988 Cost/acre ($/ac)	Annual Maint. Cost (% capital cost)
Conifers– seedlings	102	NA
Deciduous– seedlings	205	NA
Nursery stock– inexpensive species	1,025	NA
Nursery stock– expensive species	5,124	NA

MARSH BUFFER STRIP – Washington, D.C.; Schueler, 1987

	1988 Cost/acre ($/ac.)	Annual Maint. Cost (% capital cost)
Rhizomes, plugs or small pots	2,050	NA

SOD GRASS FILTER STRIPS – Wisconsin (estimated from graphs calculated from unit costs); SE Wisc. Reg Planning Comm., 1991

	Cost/acre ($/ac.)	Annual Maint. Cost (% capital cost)
40' Wide VFS	27,200	3%
60' Wide VFS	25,400	3%
80' Wide VFS	24,500	3%
100' Wide VFS	25,700	3%

SWALES

GRASS SWALES– 15 ft wide, 3:1 sideslope (approx. 2.5 ft deep)– Washington, D.C.; Schueler, 1987

Excavation/shaping plus:	1988 Cost/linear ft. ($/linear ft)	Comments
Seeding/straw mulching	4.61	more economical
Seeding/net anchoring	8.45	than the curb and
Sodding/stapling	7.94	gutter they replace

SODDED GRASS SWALES– Wisconsin (cost estimated from graph calculated from unit costs); SE Wisc. Reg. Planning Comm., 1991

	1988 Cost/linear ft. ($/lin ft)
1' bottom, 1' deep	9
10' bottom, 1' deep	15
1' bottom, 3' deep	20
10' bottom, 3' deep	28
1' bottom, 5' deep	40
10' bottom, 5' deep	50

POROUS PAVEMENT

Cost presented are Incremental Costs, ie. cost beyond that required for conventional asphalt pavement

POROUS PAVEMENT – Wisconsin (Based on unit costs); SWRPC, 1991

	Low Cost/Ac	High Cost/Ac	Moderate Cost/Ac	Annual Maint. Cost
Incremental Capital Cost/Ac (Incremental costs, i.e. cost beyond that required for conventional asphalt pavement.)	$40,051	$78,288	$59,169	$200/ac/yr* *Incremental O&M costs(includes vacuum sweeping, high–pressure jet hosing and inspections)

POROUS PAVEMENT – Washington, D.C. (Based on unit costs); Schueler, 1987

	Low Cost/Ac	High Cost/Ac	Moderate Cost/Ac	Annual Maint. Cost	Comment
Incremental Capital Cost/Ac	NA	NA	$76,916	NA	Economy of scale not evident

CONCRETE GRID PAVEMENT

Cost presented are Incremental Costs, ie. cost beyond that required for conventional asphalt pavement

CONCRETE GRID PAVEMENT – National Concrete Masonry Association (Based on unit costs)

	Low Cost/Ac	High Cost/Ac	Moderate Cost/Ac	Annual Maint. Cost	Comment
Incremental Capital Cost/Ac	NA	NA	$65,340	NA	ave. incremental costs are between $ 1.00 to $2.00 per sq. ft.

CONCRETE GRID PAVEMENT – Smith, 1981

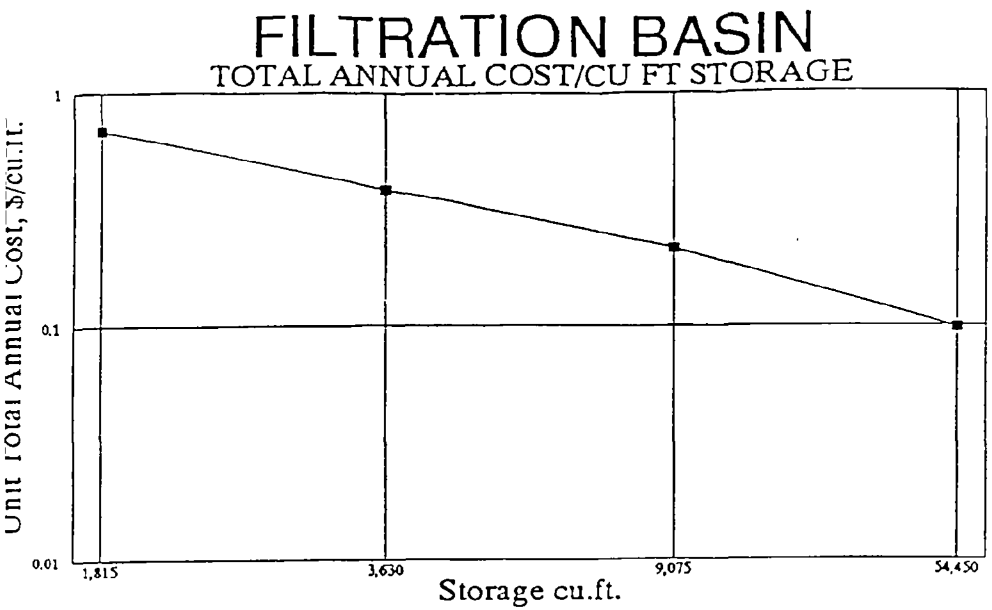
	Low Cost/Ac	High Cost/Ac	Moderate Cost/Ac	Annual Maint. Cost	Comment
Incremental Capital Cost/Ac	NA	NA	$43,560	–$1,900*	ave. incremented costs are about $ 1.00 per sq. ft. *there is a net decreased in operation and management cost for concrete pavements with life span of 20 years

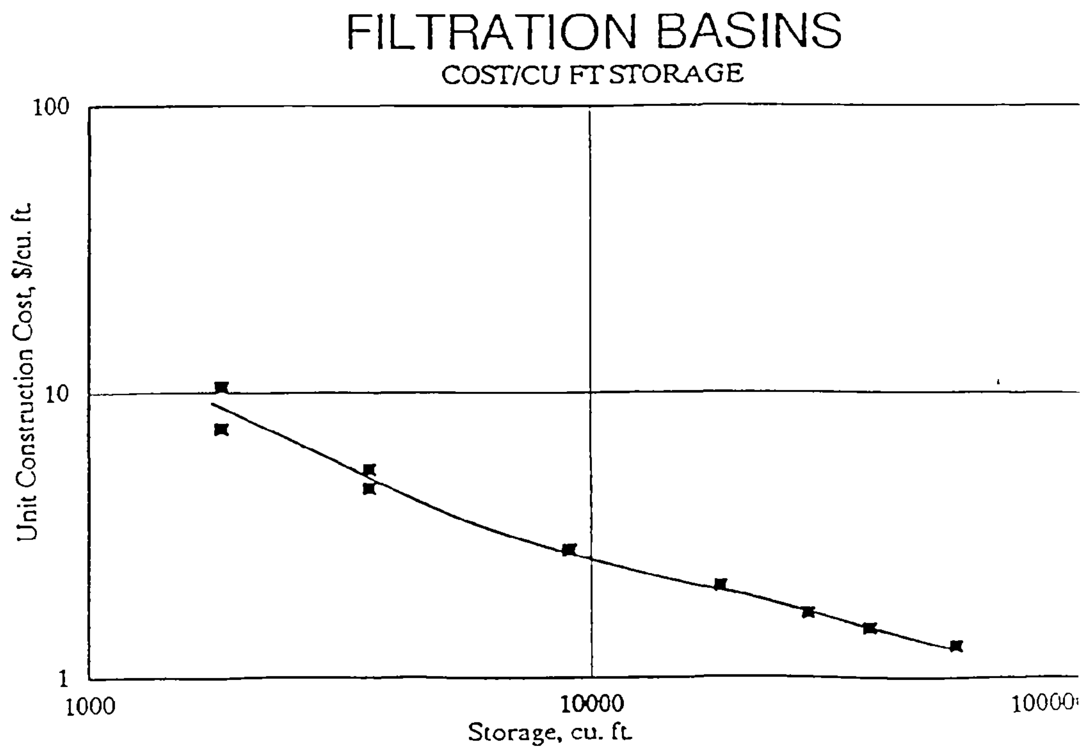
FILTRATION BASINS

SEDIMENTATION/FILTRATION BASINS– Austin, Texas (engineer's estimates); Tull, 1990

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988)	Cost/Cu.Ft. ($/cu.ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
1,815	1	13,613	7.50	13,613	NA
1,815	1	19,058	10.50	19,058	NA
3,630	2	16,880	4.65	8,440	NA
3,630	2	19,602	5.40	9,801	NA
9,075	5	25,682	2.83	5,136	NA
18,150	10	38,115	2.10	3,812	NA
27,225	15	46,283	1.70	3,086	NA
36,300	20	54,450	1.50	2,723	NA
54,450	30	70,785	1.30	2,360	NA

CHART 3. UNIT CONSTRUCTION COST AND TOTAL ANNUAL COST OF FILTRATION BASIN





WATER QUALITY INLETS/ CATCH BASINS

3 Chamber Water Quality Inlet (Oil/Grit Separator); Schueler, 1987

Storage Volume (cu.ft.)	Cost,$	Annual Maint. Cost (% capital cost)	Comments
NA	7,500	NA	ave= $ 7,000 to $ 8,000

3 Chamber Water Quality Inlet (Oil/Grit Separator) – Montgomery County, Maryland

Storage Volume (cu.ft.)	Cost/Acre $/ac.	Annual Maint. Cost (% capital cost)	Comments
NA	17,500	NA	ave= $ 15,000 to $ 20,000 per acre

Water Quality Inlet (Catch Basin with Sand Filter) – Shaver, 1991

Storage Volume (cu.ft.)	1988 Cost/Acre $/ac.	Annual Maint. Cost (% capital cost)	Comments
NA	10,000	NA	located in 1986, Maryland

Water Quality Inlet (Catch Basin) – Wisconsin, 1991

Storage Volume (cu.ft.)	Cost,$	Annual Maint. Cost (% capital cost)	Comments
NA	3,000	NA	None

Water Quality Inlet (Catch Basin) – Austin, Texas

Storage Volume (cu.ft.)	Cost,$	Annual Maint. Cost (% capital cost)	Comments
NA	1,150	NA	ave= $ 900 to $1,400, cost of standard inlets

DRY PONDS

DRY PONDS– Chester County, Penn.; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)
65,340	19	20,035	0.31	1,033
91,480	30	16,695	0.18	557
222,200	72	26,713	0.12	370
335,400	35	18,946	0.06	541

DRY PONDS– Fairfax, Virginia; APWA Res. Foundation

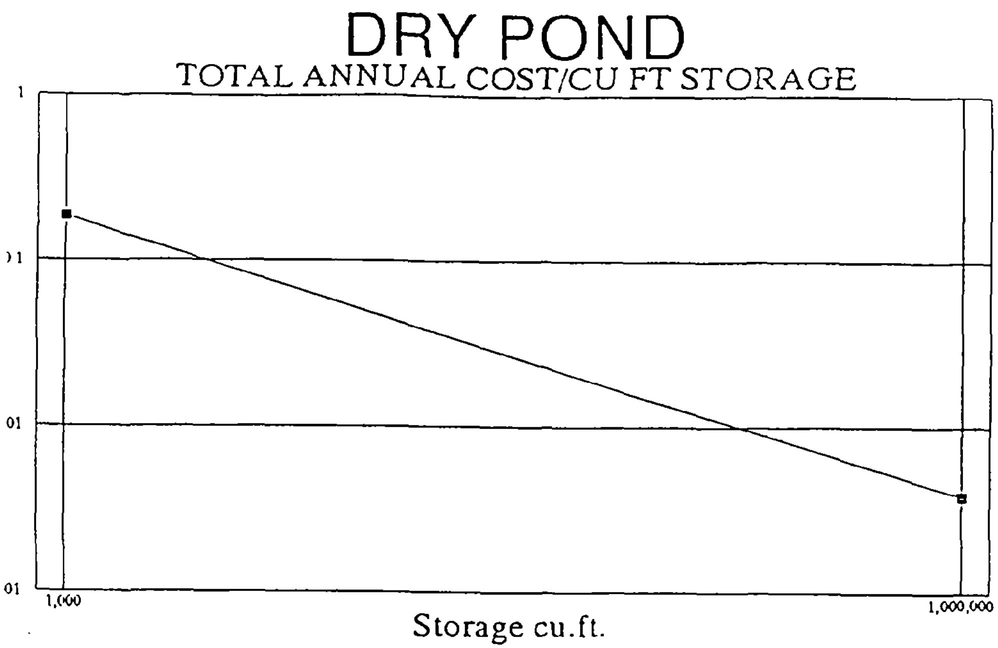
Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)
6,530	8	12,018	1.84	1448
13,940	36	11,985	0.86	337
15,250	11	7,673	0.50	731
16,120	18	5,031	0.31	287
25,260	16	9,412	0.37	592
28,310	12	11,847	0.42	982
37,900	227	7,899	0.21	35
48,790	43	12,269	0.25	286
70,570	25	6,855	0.10	278
94,960	55	15,107	0.16	276
104,110	32	6,913	0.07	218
112,820	20	12,142	0.11	611
253,080	94	20,232	0.08	215
382,020	99	50,050	0.13	507

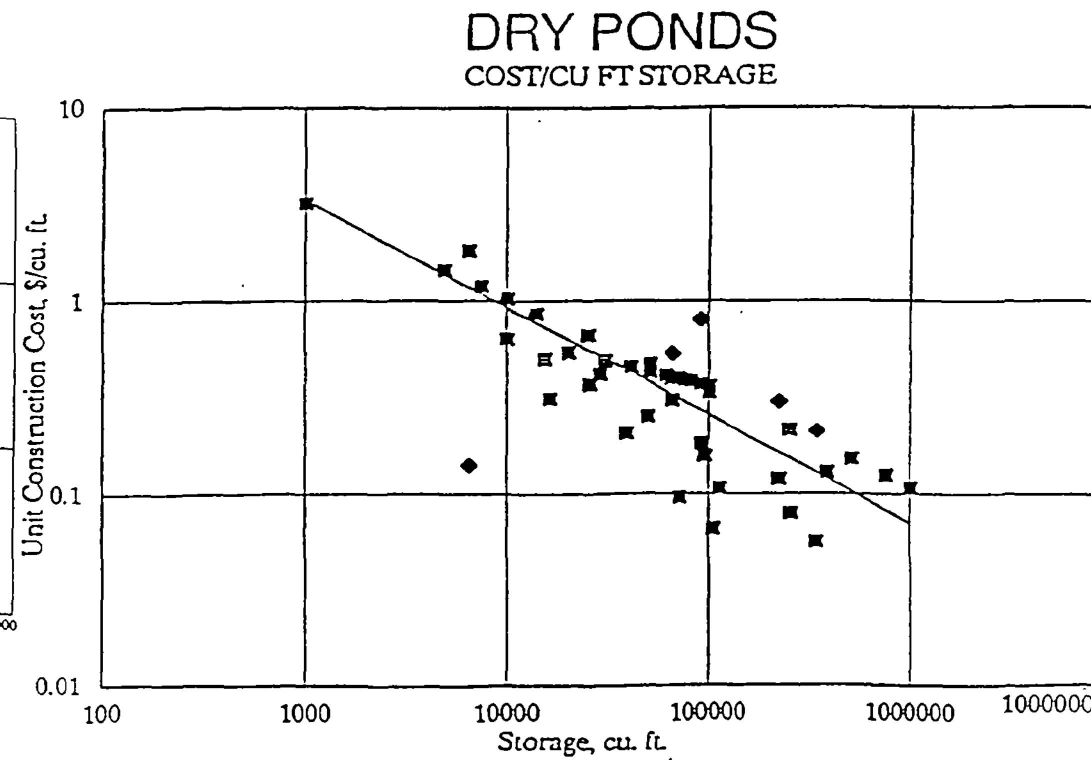
DRY PONDS– Washington, DC (based on WASHCOG NURP equation from regression analysis for approx. 30 dry ponds) EPA, 1983

C=77.4*V^0.51

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
1,000	NA	3,217	3.22	NA	3–5%
5,000	NA	7,311	1.46	NA	3–5%
7,500	NA	8,991	1.20	NA	3–5%
10,000	NA	10,411	1.04	NA	3–5%
25,000	NA	16,613	0.66	NA	3–5%
50,000	NA	23,658	0.47	NA	3–5%
75,000	NA	29,093	0.39	NA	3–5%
100,000	NA	33,691	0.34	NA	3–5%
250,000	NA	53,760	0.22	NA	3–5%
500,000	NA	76,557	0.15	NA	3–5%
750,000	NA	94,143	0.13	NA	3–5%
1,000,000	NA	109,021	0.11	NA	3–5%

CHART 4. UNIT CONSTRUCTION COST AND TOTAL ANNUAL COST OF DRY POND





ALL PONDS >10,000 cu. ft. and < 100,000 cu. ft. – Washington, D.C. (Based on equation from regression analysis from bids for 53 ponds); Wiegand, et.al., 1986

C=6.11*V^0.752

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
10,000	NA	6,419	0.64	NA	5%
20,000	NA	10,810	0.54	NA	5%
30,000	NA	14,663	0.49	NA	5%
40,000	NA	18,205	0.46	NA	5%
50,000	NA	21,531	0.43	NA	5%
60,000	NA	24,695	0.41	NA	5%
70,000	NA	27,730	0.40	NA	5%
80,000	NA	30,659	0.38	NA	5%
90,000	NA	33,498	0.37	NA	5%
100,000	NA	36,260	0.36	NA	5%

SMALL ONSITE DETENTION PONDS– Orlando, Florida; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
18,000	NA	14,400	0.80	NA	NA
160,000	NA	84,800	0.53	NA	NA
250,000	NA	75,000	0.30	NA	NA
500,000	NA	105,000	0.21	NA	NA
1,000,000	NA	140,000	0.14	NA	NA

4 DETENTION PONDS AND INTERCONNECTING PIPE – Wisconsin; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
392,040	55	158,689	0.40	2,885	NA

WET PONDS

WET PONDS – Chester County, Penn.; APWA Res. Foundation

Storage Volume (cu.ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
161,170	12	8,348	0.05	720	NA
174,240	275	61,339	0.38	223	NA
1,002,000	174	98,143	0.56	564	NA

WET PONDS – Fairfax, Virginia; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
NA	12	10,201	NA	823	NA
NA	13	4,626	NA	349	NA
NA	17	1,695	NA	102	NA
NA	27	20,677	NA	768	NA
98,880	56	7,371	0.07	132	NA
115,430	57	7,861	0.07	139	NA
NA	105	4,979	NA	47	NA

ALL PONDS >10,000 cu. ft. and < 100,000 cu. ft. – Washington, D.C. (based on equation from regression analysis from bids for 53 ponds); Wiegand, et.al., 1986

C=6.11*V^0.752

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
10,000	NA	6,419	0.64	NA	NA
20,000	NA	10,810	0.54	NA	NA
30,000	NA	14,663	0.49	NA	NA
40,000	NA	18,205	0.46	NA	NA
50,000	NA	21,531	0.43	NA	NA
60,000	NA	24,695	0.41	NA	NA
70,000	NA	27,730	0.40	NA	NA
80,000	NA	30,659	0.38	NA	NA
90,000	NA	33,498	0.37	NA	NA
100,000	NA	36,260	0.36	NA	NA

WET PONDS > 100,000 cu. ft.– Washington, D.C. (based on equation from regression analysis from bids for 13 wet ponds.); Wiegand, et.al., 1986
$C=33.99*V^{0.644}$

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
100,000	NA	58,176	0.58	NA	NA
125,000	NA	67,167	0.54	NA	NA
150,000	NA	75,535	0.50	NA	NA
175,000	NA	83,418	0.48	NA	NA
200,000	NA	90,909	0.45	NA	NA
225,000	NA	98,073	0.44	NA	NA
250,000	NA	104,958	0.42	NA	NA
500,000	NA	164,014	0.33	NA	NA
750,000	NA	212,953	0.28	NA	NA
1,000,000	NA	256,297	0.26	NA	NA
10,000,000	NA	1,129,129	0.11	NA	NA
20,000,000	NA	1,764,440	0.09	NA	NA
30,000,000	NA	2,290,918	0.08	NA	NA

WET PONDS – Washington, D.C.; Schueler, 1987

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
NA	NA	NA	NA	NA	3–5%

SMALL ONSITE DETENTION PONDS– Orlando, Florida (in text and estimated off graph); APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
18,000	NA	14,400	0.80	NA	NA
160,000	NA	84,800	0.53	NA	NA
250,000	NA	75,000	0.30	NA	NA
500,000	NA	105,000	0.21	NA	NA
1,000,000	NA	140,000	0.14	NA	NA

OFFSITE DETENTION PONDS CREATED FROM NATURAL LOW AREAS– Orlando, Florida; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
250,000	NA	40,000	0.16	NA	NA
500,000	NA	55,000	0.11	NA	NA
1,000,000	NA	50,000	0.05	NA	NA
2,000,000	NA	80,000	0.04	NA	NA

OFFSITE DETENTION PONDS REQUIRING SUBSTANTIAL EXCAVATION – Orlando, Florida; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
500,000	NA	505,000	1.01	NA	NA
1,000,000	NA	760,000	0.76	NA	NA
2,000,000	NA	1,000,000	0.50	NA	NA

WET PONDS WITH PUMPED REMOVAL – Chicago, Ill.; APWA Res. Foundation

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
26,100,000	13,250	5,380,346	0.21	406	NA

WET PONDS – Tri-County, Michigan; SE Wisc. Reg. Planning Comm., 1991

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
283,140	NA	81,243	0.29	NA	2.5%

WET PONDS – Southeastern Wisconsin; SE Wisc. Reg. Planning Comm., 1991

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
43,560	NA	32,542	0.75	NA	NA
130,680	NA	61,460	0.47	NA	NA
217,800	NA	94,022	0.43	NA	NA
435,600	NA	146,492	0.34	NA	NA
871,200	NA	227,900	0.26	NA	NA

WET PONDS – Southeastern Wisconsin (estimated from graphs caluculated from unit costs); SWRPC, 1991

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
30,000	NA	25,000	0.83	NA	5%
50,000	NA	31,000	0.62	NA	4%
75,000	NA	40,000	0.53	NA	4%
100,000	NA	48,000	0.48	NA	4%
250,000	NA	100,000	0.40	NA	3%
500,000	NA	200,000	0.40	NA	3%
1,000,000	NA	330,000	0.33	NA	3%

WET PONDS – Salt Lake County, Utah; SE Wisc. Reg. Planning Comm., 1991

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
NA	160	53,068	NA	NA	1.5%

WET PONDS – Fresno, California; SE Wisc. Reg. Planning Comm., 1991

Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)	Annual Maint. Cost (% capital cost)
NA	NA	1,231,163	NA	NA	0.5%
NA	NA	1,716,868	NA	NA	0.3%
NA	NA	7,207,230	NA	NA	<0.1%
NA	NA	1,201,538	NA	NA	0.9%

NA: Not Available

CHART 5. UNIT CONSTRUCTION COST AND TOTAL ANNUAL COST OF WET AND EXTENDED DETENTION WET PONDS