URBAN BMP COST AND EFFECTIVENESS

SUMMARY DATA

FOR 6217(g) GUIDANCE

ROADS, HIGHWAYS, AND BRIDGES

January 29, 1993

WOODWARD-CLYDE

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1.0 INTRODUCTION

In November 1990, the U.S. Congress reauthorized 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 National Oceanic and Atmospheric Administration (NOAA) jointly drafted Proposed Program Guidance for Section 6217 of CZARA. EPA has lead responsibility for developing the Management Measures Guidance required under Section 6217(g).

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 management practices for roads, highways and bridges. The report also contains information regarding the pollutants found in the runoff from highways and appropriate management practices and systems of management practices for the control of (NPS) pollution.

This document contains information from over 40 documents. Over 200 documents were reviewed regarding roads, highways and bridges 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. 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. It should be noted that the documents obtained and reviewed do not include all of the published literature regarding roads, highways and bridges management practices. However, many of the documents obtained were summaries of many other investigations.

Section 2.0 contains descriptions of the pollutants found in runoff from highways. Sections 3.0 through 6.0 describe the management practices available for the control of nonpoint source pollution from roads, highways and bridges. These practices have been divided into four categories: planning and design (Section 3.0), erosion and sediment control during construction (Section 4.0), storm water runoff treatment (Section 5.0),and operation and maintenance (Section 6.0). Section 7.0 describes some management practice options. Roads, highways and streets are referred to throughout this section. The following defines what is meant by a road, highway or street in this guidance document.

Roads

Roads are defined as public ways for purposes of vehicular travel and access to adjacent property. Roads are usually designed without curb and gutter and with grassed swales to handle drainage. Roads are generally located in rural areas and can be paved or unpaved.

Streets

Streets are dedicated public rights-of-way for access to abutting residential and other urban properties. Streets are usually designed with curbs and gutters and drainage inlets. Streets are generally located in urban areas, rural and suburban subdivisions and are mostly paved. The terms for "streets" and "roads" are often used interchangeably.

Highways

A general term denoting a public right-of-way for purposes of vehicular travel. Highway systems include the National Highway System and the Interstate System.

The Appendix presents the data analyzed to develop summary cost and effectiveness information.

2.0
POLLUTANTS FROM ROADS, HIGHWAYS, AND BRIDGES

Automobiles generate pollutants that are deposited on street surfaces through wear and corrosion of parts, leaking oils and lubricants, and combustion by-products. A wide range of pollutants are generated, but the main pollutants of concern are metals and hydrocarbons, which are often found at high concentrations on street surfaces. (British Columbia Research Corp., 1991) Table 2-1 lists the pollutants commonly found in stormwater runoff from roads, highways and bridges and their sources. The disposition and subsequent magnitude of pollutants found in highway runoff are site-specific and affected by traffic volume, road or highway design, surrounding land use, climate, and accidental spills.

As summarized in Pollutant Loadings and Impacts from Highway Stormwater Runoff (Driscoll et al., 1990), the Federal Highway Administration (FHWA) has conducted an extensive field monitoring and laboratory analysis program to determine the pollutant concentrations in highway runoff. Data from 993 highway runoff events at 31 sites in 11 states were analyzed and the results are shown in Table 2-2. The concentration is given as an event mean concentration (EMC). This is the median of all the average concentrations of a pollutant in the total runoff volume produced by an individual storm event.

The pollutant concentrations were found to fall into two distinct groups depending on whether the highway was located in an urban or a rural setting. An urban highway is defined as a road with average daily traffic more than 30,000 vehicles. A rural highway is defined as a road with average daily traffic less than 30,000 vehicles.

The research indicated that for highways discharging to lakes, the pollutants of major concern are phosphorus and heavy metals. For highways discharging to streams, the pollutants of major concern are heavy metals - copper, lead and zinc.

EPA has developed pollutant criteria for protecting freshwater aquatic life (see Table 2-3). The Acute Criteria area based on the result of 96-hour test exposures using the continuous exposure concept. The Threshold Effect Level is the concentration that causes mortality of the most sensitive individual of the most sensitive species. This addresses the phenomena that stormwater runoff typically produces short-duration intermittent exposure to pollutants.

TABLE 2-1. HIGHWAY RUNOFF CONSTITUENTS AND THEIR PRIMARY SOURCES

POLLUTANTS	PRIMARY SOURCES
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Auto body rust, steel highway structures (guard rails, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, break lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Cyanide	Anticake compound (ferric ferrocyanide, sodium ferrocyanide, yellow prussiate of soda) used to keep deicing salt granular
Sodium, Calcium, Chloride	Deicing salts
Sulphate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
PCB	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires

Source: U.S. DOT, FHWA, Report No. FHWA/RD-84/07-060, June 1987.

TABLE 2-2. SITE MEDIAN CONCENTRATIONS IN HIGHWAY RUNOFF

A. URBAN HIGHWAYS - AVERAGE DAILY TRAFFIC USUALLY MORE THAN 30,000 VEHICLES PER DAY			
	SITE MEDIAN EMC CONCENTRATION IN mg/l		
	PERCENT OF SITES HAVING A MEDIAN EMC LESS THAN INDICATED CONCENTRATION		
POLLUTANT	10% OF SITES	50% MEDIAN SITE	90% OF SITES
TSS	68	142	295
VSS	20	39	78
TOC	8	25	74
COD	57	114	227
NO2+3	0.39	0.76	1.48
TKN	1.06	1.83	3.17
PO4-P	0.15	0.40	1.06
COPPER	0.025	0.054	0.119
LEAD	0.102	0.400	1.562
ZINC	0.192	0.329	0.564
B. RURAL HIGHWAYS - AVERAGE DAILY TRAFFIC USUALLY LESS THAN 30,000 VEHICLES PER DAY			
TSS	12	41	135
VSS	6	12	25
TOC	4	8	17
COD	28	49	85
NO2+3	0.23	0.46	0.91
TKN	0.34	0.87	2.19
PO4-P	0.06	0.16	0.48
COPPER	0.010	0.022	0.050
LEAD	0.024	0.080	0.272
ZINC	0.035	0.080	0.185
Source: Driscoll et al., 1990			

TABLE 2-3. CONCENTRATIONS FOR TOXIC EFFECTS

SURFACE WATER TOTAL HARDNESS (PPM)	EPA ACUTE CRITERIA (mg/l)			EPA NURP SUGGESTED THRESHOLD EFFECT LEVEL (mg/l)		
	COPPER	LEAD	ZINC	COPPER	LEAD	ZINC
50	0.009	0.034	0.181	0.020	0.150	0.380
60	0.011	0.043	0.210	0.025	0.200	0.440
80	0.014	0.061	0.267	0.030	0.250	0.560
100	0.018	0.082	0.321	0.040	0.350	0.675
120	0.021	0.103	0.374	0.045	0.450	0.785
140	0.024	0.125	0.425	0.055	0.550	0.890
160	0.028	0.149	0.475	0.065	0.650	1.000
180	0.031	0.173	0.523	0.070	0.750	1.100
200	0.034	0.197	0.571	0.080	0.850	1.200
220	0.037	0.223	0.618	0.090	0.950	1.300
240	0.040	0.249	0.664	0.095	1.050	1.400
260	0.044	0.276	0.710	0.100	1.200	1.500
280	0.047	0.303	0.755	0.110	1.300	1.600
300	0.050	0.331	0.800	0.115	1.400	1.700

NOTE: THRESHOLD EFFECT LEVEL - The concentration that causes mortality of the most sensitive individual of the most sensitive species

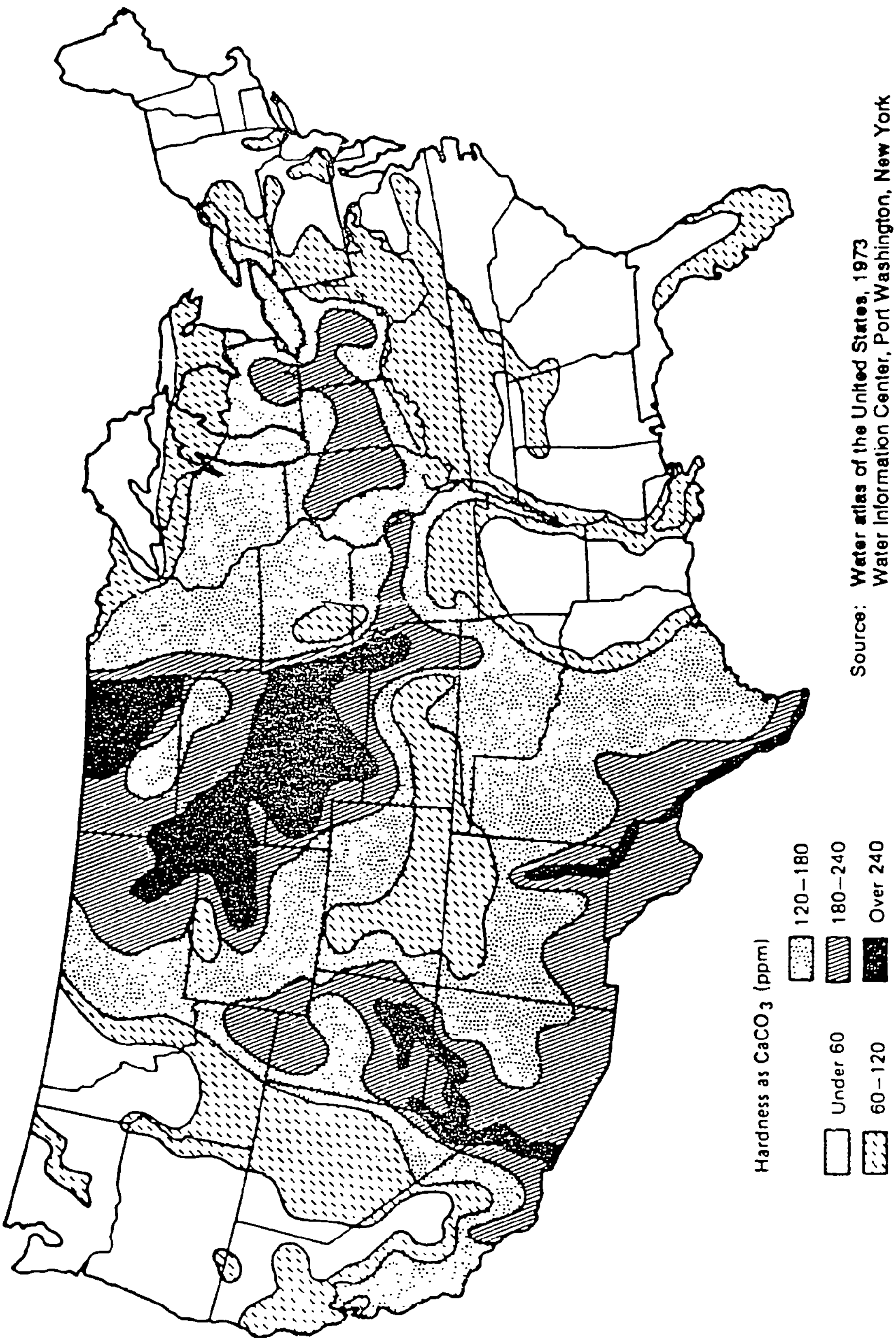
Source: Driscoll et al., 1990

EPA has developed pollutant criteria for protecting freshwater aquatic life (see Table 2-3). The Acute Criteria are based on the result of 96-hour test exposures using the continuous exposure concept. The Threshold Effect Level is the concentration that causes mortality of the most sensitive individual of the most sensitive species. This addresses the phenomena that stormwater runoff typically produces short-duration intermittent exposure to pollutants. The criteria varies with the hardness of the water, which varies regionally as shown in Figure 2-1. For additional information on Acute Criteria and Threshold Effect Level see Driscoll et al., 1990.

In coastal areas, which often have low hardness, the copper and lead concentrations from highway runoff can exceed the Threshold Effect Level. Copper, lead and zinc concentrations typically exceed the Acute Criteria.

In colder regions where deicing agents are used, deicing chemicals and abrasives are the largest source of pollutants during winter months. Deicing salt (primarily sodium chloride, NaCl) is the most commonly used deicing agent. Potential pollutants from deicing salt includes sodium, chloride, ferric ferrocyanide (used to keep the salt in granular form), and sulphate. Table 2-4 summarizes potential environmental impacts caused by road salt. Other chemicals used as a salt substitute include calcium magnesium acetate (CMA), and less frequently, urea and glycol compounds. Researchers have differing opinions on the environmental impacts of CMA compared to road salt (Salt Institute, undated) (Chevron Chemical Company, 1991) and (Transportation Research Board, 1991).

FIGURE 2-1. TOTAL HARDNESS LEVELS OF SURFACE WATERS IN THE CONTINENTAL UNITED STATES



Source: Driscoll et al., 1990

TABLE 2-4. POTENTIAL ENVIRONMENTAL IMPACTS OF ROAD SALT

Environmental Resource	Potential Environmental Impact of Road Salt (NaCl)
Soils	May accumulate in soil. Breaks down soil structure, increases erosion. Causes soil compaction that results in decreased permeability.
Vegetation	Osmotic stress and soil compaction harm root systems. Spray causes foliage dehydration damage. Many plant species are salt sensitive.
Groundwater	Mobile Na and Cl ions readily reach groundwater. Increases Na and Cl concentrations in well water as well as alkalinity and hardness.
Surface Water	Causes density stratification in ponds and lakes that can prevent reoxygenation. Increases runoff of heavy metals and nutrients through increased erosion.
Aquatic Life	Monovalent Na and Cl ions stress osmotic balances. Toxic levels: Na - 500ppm for stickleback; and Cl - 400 ppm for trout.
Human/Mammalian	Sodium is linked to heart disease and hypertension. Chlorine causes unpleasant taste in drinking water. Mild skin and eye irritant. Acute oral LD50 in rats is approximately 3000mg/kg (slightly toxic).

Source: Chevron, 1991

With proper planning and design the pollutant loads generated from roads, highways, and bridges can be minimized. Proper planning and design are often the most cost effective management practices because they reduce the requirements and costs for stormwater runoff treatment and operation and maintenance management practices. The Federal Highway Administration (FHWA) has developed a computer model that can be used in the planning process to examine the impacts of road projects. The following is a discussion of planning and design management practices available.

3.1 LOCATE PROJECT AWAY FROM CRITICAL AREAS

A road's impact on nonpoint source pollution should be considered early in the planning process. Early identification of sensitive land or water areas, and incorporating information about these areas in planning, can often prevent disturbance of these areas. Every possible means should be used to avoid disturbing wooded areas, wetlands, floodplains, ponds, rivers and streams (AASHTO, 1991). In addition, buffers should be provided between a highway and water body to protect the waterbody.

3.2 DESIGN ROADWAYS TO FIT TERRAIN

A roadway should be designed to minimize the amount of disturbance. A roadway should be constructed as close to existing grade as possible to minimize the area that must be cut or filled. However, when cut or fill is required, the slope must be designed to keep stormwater runoff velocities below erosive levels. AASHTO has location and design guidelines available for state highway agency use that describe the considerations necessary to control highway-related pollutants (AASHTO, 1991).

3.3 REDUCE USE OF CURB

Where practical, vegetative systems should be used instead of curbs. Curb systems capture and accumulate pollutants between storms, as well as concentrate runoff. This increases the pollutant load in the stormwater runoff. Without a curb system, the pollutants are blown to the shoulder and right-of-way which reduces the pollutant load available to the runoff.

A vegetative system such as grassed swales or vegetative buffer strips reduce pollutant loads as will be discussed in Section 5.0.

3.4 OBTAIN WIDER RIGHTS-OF-WAY

Where possible, rights-of-way widths sufficient to implement the structural management practices should be obtained.

3.5 REDUCE USE OF SCUPPER DRAINS

Scupper drains are used on bridges to collect stormwater runoff which is then discharged directly below the bridge. The use of scupper drains should be minimized. Where possible the bridge's stormwater runoff should be collected, piped and treated in a treatment facility located on the adjacent land.

3.6 PROTECT BRIDGES FROM SCOUR

If scour is likely to occur, the bridge piers and abutments should be designed to provide protection against scour damage. Embankment slopes that are adjacent to structures subject to erosion, should be adequately protected by flexible mattresses, rip-rap, spur dikes or other appropriate construction.

4.0
MANAGEMENT PRACTICES - EROSION AND SEDIMENT CONTROL DURING CONSTRUCTION

Erosion and sediment controls should be used during the construction of roads, highways and bridges. The controls are needed because soil eroded from construction sites may contaminate lakes, streams, and reservoirs, restrict drainage ways, plug culverts, damage adjacent properties, and affect the ecosystems of streams (AASHTO, 1990). According to Section 650B of the Federal-Aid Policy Guide, all Federal-aid highways and highways constructed under the direct supervision of the Federal Highway Administration must be constructed and operated so that erosion and sediment damage to the highway and adjacent properties is minimized.

Erosion and sedimentation from construction of roads, highways, and bridges, and from unstabilized cut-and-fill areas, can significantly impact receiving waters and wetlands with silt and other pollutants including heavy metals, hydrocarbons, and toxic substances. Erosion and sediment control plans are effective in describing procedures for mitigating erosion problems at construction sites before any land disturbing activity begins.

Bridge construction projects include grade separations (bridges over roads) and waterbody crossings. Erosion problems at grade separations result from water running off the bridge deck and runoff waters flowing onto the bridge deck during construction. Controlling this runoff can prevent erosion of slope fills and the undermining failure of the concrete slab at the bridge approach. Bridge construction over waterbodies requires careful planning to limit the disturbance of streambanks. Soil materials excavated for footings in or near the water should be removed and relocated to prevent the material from being washed back into the waterbody. Protective berms, diversion ditches, and silt fences parallel to the waterway can be effective in preventing sediment from reaching the waterbody.

Detailed information on erosion and sediment control management practices, their effectiveness and cost, and recommended management practices can be found in <u>Urban BMP Cost and Effectiveness Summary Data for 6217(g) Guidance - Erosion and Sediment Control During Construction</u> (Woodward-Clyde, 1993). The following is a list of the various erosion and sediment control management practices:

- Schedule projects so clearing and grading is done during time of minimum erosion potential
- Stage construction
- Only clear areas essential for construction
- Avoid disturbing vegetation on steep slopes or other critical areas
- Route traffic to avoid existing or newly planned vegetation construction
- Protect natural vegetation with fencing, tree armoring, and retaining walls or tree wells
- Seed and fertilize
- Seed and mulch
- Mulching
- Sodding
- Where practical stockpile topsoil and reapply to revegetate site
- Cover or stabilize topsoil stockpiles
- Wind erosion controls
- Intercept runoff above disturbed slopes and convey it to a permanent channel or storm drain
- On long or steep disturbed or man-made slopes, construct benches, terraces, or ditches at regular intervals to intercept runoff
- Provide linings for channels
- Check dams
- Sediment basins
- Sediment traps
- Filter fabric fences
- Straw bale barriers
- Inlet protection
- Construction entrances
- Vegetative filter strips

5.0 MANAGEMENT PRACTICES - STORMWATER RUNOFF TREATMENT

The Federal Highway Administration (FHWA) has completed a four phase research program to identify and quantify the effects of highway runoff and develop management measures to protect receiving waters. The research resulted in a list of cost-effective structural management practices for use on highway projects (Hartigan et al, 1989):

- Vegetative controls (includes vegetative filter strips and grassed swales)
- Wet detention ponds
- Extended detention dry ponds
- Infiltration basins
- Wetlands.

These practices, along with extended detention wet ponds can also be effective for controlling runoff from non-highway roads.

This section will describe these management practices and the cost and effectiveness of the systems. In addition, the Federal Highway Administration developed an interactive computer model which can be used on specific sites to model the effectiveness of vegetative filter strips (overland flow), grassed swales, detention or wet ponds, and infiltration devices (Dorman et al, 1989).

The FHWA research also identified some ineffective measures for highway projects (Hartigan et al, 1989):

- Catch basins
- Porous pavement
- Street cleaning
- Filtration devices for sediment control.

Although catch basins and porous pavement are not effective for highways, they may be effective for some roadways and parking lots and are discussed in this section. Street cleaning is also not effective for highways. However, other research has indicated that street cleaning may be effective under certain circumstances in urban areas. This research will be discussed in Section 6.0 of this report (Operation and Maintenance).

Filtration devices for sediment control includes straw bales, filter fabric fence, and gravel filters. These practices are generally effective for filtering out large sized particles but are ineffective for trapping finer solids. This makes these devices generally effective for sediment control during construction but not for control of post-construction highway runoff. The use of these devices are discussed in a separate report - Urban BMP Cost and Effectiveness Summary Data for 6217(g) Guidance - Erosion and Sediment Control During Construction (Woodward-Clyde, 1993).

Section 5.1 describes the management practices available. Section 5.2 summarizes the advantages and disadvantages, effectiveness, and cost of the practices. Section 5.3 further discusses the practices' effectiveness and the basis for determining effectiveness and Section 5.4 further discusses the practices' cost and the basis for determining cost.

5.1 DESCRIPTION

The Stormwater Runoff Treatment Management Practices have been divided into two categories. Those typically effective for highways and roads and those typically not effective for highways but are effective for other roadways. The following is a description of various road and highway stormwater runoff structural management practices. In addition to providing pollutant removal, several practices can also control the post-development peak flow rate which is important for protecting downstream channels from erosion due to increased velocities and runoff volumes.

5.1.1 Highways and Roads

Vegetative Filter Strips

Vegetative filter strips are similar to grass swales, except 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 and grassed swales are the most commonly used management practices along highways. These practices are often used because they are adaptable to many site conditions, are flexible in design and layout and are relatively inexpensive. Vegetative filter strips may be used alone or they may be used as pretreatment to other management practices such as infiltration basins or ponds (Dorman et al, 1989).

Vegetative filter strips should have relatively low slopes, adequate length, and be planted with erosion resistant plant species. Vegetative filter strips which 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 and years after construction to make sure a dense, vigorous vegetation is established and the flow does not concentrate.

If natural vegetative succession is allowed to proceed, little other maintenance is required. 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. Accumulated sediment must also be periodically removed near the top of the strip (Schueler, 1987).

Grassed Swales

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

Grassed swales and vegetative filter strips are the most commonly used management practices along highways. These practices are often used because they are adaptable to many site conditions, are flexible in design and layout and are relatively inexpensive. Grassed swales may be used alone or as pretreatment to other management practices such as infiltration basins or ponds (Dorman et al, 1989).

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).

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 similar routine maintenance as 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). However, a study conducted in Florida found that the bottom sediment sampled from nine ponds that received runoff water from highways all had metal concentrations measured well below the regulatory level to be considered hazardous waste. Therefore, the sediment can be used if some form if fill is needed such as noise barriers (berms), highway slopes, or eroded areas. The study also predicted a required dredging cycle between 7 and 47 years with an average of approximately 25 years (Yousef et al, 1991).

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.

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 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, and detention time and degree of maintenance provided.

Operation and Maintenance

Extended wet ponds require maintenance and have a useful life similar to those for wet ponds.

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, which allows the solids time to settle out. Extended detention dry ponds are typically comprised of two stages: an upper stage which 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 usually 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 typically cannot 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.

Operation and Maintenance

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

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 dry 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). However, a study conducted in Florida found that the bottom sediment sampled from nine ponds, which received runoff water from highways, all had metal concentrations measured well below the regulatory level to be considered hazardous waste. Therefore, the sediment can be used if some form if fill is needed such as noise barriers (berms), highway slopes, or eroded areas. The study also predicted a required dredging cycle between 7 and 47 years with an average of approximately 25 years (Yousef et al, 1991).

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.

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 are therefore 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 pore on the basin floor. If there is concentrated flow, a sediment trap could be used. 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 problem with the basins were inappropriate ponding of water and excessive sediment and debris (Lindsey, 1991).

Infiltration basins which 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 basins useful life may be shortened due to clogging.

Infiltration basins are easier to maintain than infiltration trenches because infiltration trenches are more susceptible to clogging from sediment, oil, and grease from highway runoff. Therefore, infiltration basins are the preferred management practices for highways (Dorman et al, 1989).

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 typically are not 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.

5.1.2 Roads Only

Infiltration Trenches and Dry Wells

Infiltration trenches and dry wells are shallow excavated holes or ditches that have been back-filled 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. This is needed 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 these 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 problem with the trenches were excessive sediment loads and clogging (Lindsey, 1991).

Porous Pavement

Porous pavement, an alternative to conventional pavement, reduces much of the need for drainage conveyance and treatment of the runoff from the pavement area. Instead, 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 are high traffic volumes 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).

Concrete Grid Pavement

Concrete grid pavement, sometimes referred to as "grasscrete," consists of concrete blocks with regularly interspersed void areas which 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. In addition, concrete grid pavement with grass require at least five hours of sunlight daily for most grass species to survive. Also, there must 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 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 adverse 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).

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. In addition, 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. In addition, the accumulated sediment should be periodically removed and the filter media with sediment depositions should be removed and replaced.

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 disposed 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.

Water Quality Inlet - Catch Basin With Sand Filter

Catch basins with sand filter 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 of 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. In addition, periodically the accumulated sediment in the sedimentation chamber should be removed (Shaver, 1991). However, no acceptable clean-out and disposed 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.

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 oil-water separator. Cleaning the oil/grit separators at regular intervals will prevent the accumulated debris and oil to be discharged from the structure during intense storms. An oil/grit separator typically should be cleaned at least four times a year. However, no acceptable clean-out and disposed 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.

5.2 SUMMARY OF ADVANTAGES, DISADVANTAGES, EFFECTIVENESS AND COST

This section presents summary tables (Tables 5-1, 5-2, and 5-3) for various management practices. The information presented in this section is summarized in the following tables:

- Table 5-1 summarizes the advantages and disadvantages of the various management practices.

- Table 5-2 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 5-2.

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 5-2 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 5.3, and the references considered in developing the 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 5-2. 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 5-1. 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 5-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (Cont'd)

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 5-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (Cont'd)

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 5-1 ADVANTAGES AND DISADVANTAGES OF MANAGEMENT PRACTICES[1] (Cont'd)

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 5-2 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 5-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OR RUNOFF FROM NEWLY DEVELOPED AREAS (Cont'd)

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 5-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OR RUNOFF FROM NEWLY DEVELOPED AREAS (Cont'd)

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 • Sedimentation storage volume	Pitt, 1986; Field, 1985; Schueler, 1987
	Reported Range:	0-95	5-10	5-55	5-10	10-25	5-10		
	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 • 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		
OIL/GRIT SEPARATOR (7)	Ave:	15	5	5	5	15	5	• Sedimentation storage volume • Outlet configurations	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		
	Number of References	2	1	1	1	1	1		
EXTENDED DETENTION DRY POND	Ave:	45	25	30	20	50	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 (5):	70-90	10-60	20-60	30-40	20-60	40-60		
	No. Values Considered:	6	6	4	5	4	5		

TABLE 5-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OR RUNOFF FROM NEWLY DEVELOPED AREAS (Cont'd)

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

TABLE 5-2 EFFECTIVENESS OF MANAGEMENT PRACTICES FOR CONTROL OR RUNOFF FROM NEWLY DEVELOPED AREAS (Cont'd)

(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 5-3 presents construction and annual maintenance cost information. In this table, the cost information is annualized so that comparisons can be made from one practice to another. To analyze the cost an interest rate of 5% was assumed. Some practices have limited useful lives. However, other practices will continue to provide water quality benefits indefinitely if properly maintained. In order to analyze the capital costs of those practices, they were assumed to have a useful life of 50 years. The 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 costs.

These summary tables are based on the detailed cost and effectiveness data presented in the Appendix. Additional effectiveness and cost information follows the tables in Section 5.3 and 5.4.

TABLE 5-3. 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 5-3. COST OF MANAGEMENT PRACTICES FOR CONTROL OF RUNOFF FROM NEWLY DEVELOPED AREAS (Cont'd)

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.

5.3 EFFECTIVENESS

Factors that influence the effectiveness of the various management practices are shown in Table 5-2. 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 A.

5.3.1 Highways and Roads

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 typically only a small portion of the runoff infiltrates. Forested filter strips appear to be more effective than grassed strips, but a longer length is required for optimal removal rates (Schueler, 1987).

The pollutant removal rates of vegetative filter strips can be increased by increasing the travel time and decreasing the flow depth. Factors that affect the travel time and flow depth are drainage area, slope, length and type of vegetative cover (Dorman et al, 1989).

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. In order to provide probable removal rates that could be used at the planning level, Table 5-2 was developed from the chart prepared by Dorman et al, 1989 for the Federal Highway Administration (FWHA).

The FHWA report (Dorman, 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. In order to estimate removal rates probably provided from properly designed urban VFSs using the chart prepared by Dorman et al, the depth of flow was assumed to be less than 4 inches. 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 the reported ranges in the 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 5-2 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.

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). In general swales are not 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).

To have significant pollutant removal rates, grassed swales must have long hydraulic travel times and low flow depth. This is often achieved along highways where there are long lengths of grassed swales. However, along urban roads where travel lengths are typically short, removal rates are low.

The pollutant removal rates of grass channels can be increased by increasing the travel time and decreasing the flow depth. Factors that affect the travel time and flow depth are drainage area, slope, length, swale width and slide slopes and type of vegetative cover (Dorman 1989).

The probable removal rates for grassed swales were obtained from the above chart discussed for vegetative filter strips. The removal efficiency for grassed swales along roads and highways is higher than for grassed swales in other urban areas, because they are typically much longer and therefore have longer travel times.

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.

Wet Ponds

The principle removal mechanisms are sedimentation of the particulate pollutants and biological uptake of soluble nutrients (Dorman, 1989). Wet ponds are very effective in removing pollutants if the detention time is long enough to allow the pollutants to settle out. Pollutant removal rates have been found to be from low to high depending on the size of the basin relative to its drainage area (Dorman, 1989).

Twenty-four sets of information on wet ponds' removal efficiencies were available in Schueler et al, 1992. Current literature indicate 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 5-2 show the range of the remaining efficiencies.

Extended Detention Wet Ponds

The principal removal mechanisms are sedimentation of the particulate pollutants and biological uptake of soluble nutrients. The upper stage of the extended detention wet pond should be planted with marsh plants which increase the biological uptake.

Data on removal efficiencies for three extended detention wet ponds were available in Schueler et al, 1992. Table 5-2 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).

Extended Detention Dry Ponds

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 dry 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.

Infiltration Basins

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 were very little published data on effectiveness of infiltration basins or infiltration trenches, the efficiencies shown as the probable range in Table 5-2 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" (Woodward-Clyde, 1986) 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 the model "STORM," and "SWMM."

In order 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 5-2, 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. In order to account for regional differences, the model was run for four different rainfall regions. Regional rainfall data was obtained from "Analysis of Storm Event Characteristics for Selected Rainfall Gages Throughout the United States" (Woodward-Clyde, 1989). The analysis was performed for four CZMA 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. Only permeable soils (SCS soil type A or B) should be used with infiltration devices. 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

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

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 5-2 is for the designs with a minimum area of wetlands 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.

5.3.2 Roads Only

Infiltration Trenches

See infiltration basins in Section 5.3.1 for effectiveness information.

Porous Pavement

Two porous pavement studies were cited in the literature. They both obtained relatively high pollutant removal rates. However, as previously stated, 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.

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 which 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.

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. In addition, based on these results the report estimated expected removal rates for several possible designs. 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 5-2 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, since during large storms some of the runoff will not be treated, 100% removal does not seem realistic. Instead it was reduced to 90% for Table 5-2. In addition, the expected removal rates do not include COD, so the COD removal rates reported from the monitoring study were used.

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.

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.

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 separator 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.

Porous pavement, concrete grid pavement, water quality inlets - catch basins, water quality inlets - catch basins with sand filter, and water quality inlets - oil/grit separator are the post-construction stormwater runoff treatments, which are effective for some urban roads and parking lots but not highways.

5.4 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 but are not recommended for use in estimating and 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 were presented in Table 5-3 of this report. Table 5-3 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 Appendix B.

The costs presented are only construction costs. They do 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.

5.4.1 Highways and Roads

Vegetative Filter Strip

The cost of VFS is dependent on the type of vegetation. 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.

Grassed Swales

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. Approximate costs are given in Table 5-3.

Wet Ponds

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.

Extended Detention Wet Ponds

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 west ponds will be minimal. Therefore, it was assumed that wet ponds and extended detention wet ponds have the same cost.

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 and are shown in Table 5-3. In addition, Chart 4, in Appendix C, shows the economy of scale for extended detention dry ponds.

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.

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 (Schueler et al, 1992).

5.4.2 Roads Only

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.

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.

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 involved, 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 pavements installed in place and annual maintenance cost presented in Table 5-3 are based on information provided by NCMA.

Filtration Basin

Data regarding the cost 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.

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).

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).

Water Quality Inlet - Oil/Grit Separator

The cost of the oil/grit separator will depend on the storage volume of the chambers which 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.

6.0 OPERATION AND MAINTENANCE

Operation and maintenance procedures that can be used to reduce or eliminate nonpoint source pollution fall into four general categories: maintenance of vegetation, street cleaning, deicing chemical use management, and containment bridge maintenance.

Maintenance of vegetation is important for keeping a vigorous vegetation which provides erosion control and pollution reduction.

Street cleaning removes potential sources of storm water runoff pollution and therefore reduces the pollutant loads in the runoff.

Deicing chemical use management reduces the amount of stormwater runoff pollution caused by deicing chemicals. Sodium chloride, which is found in deicing salts, have high water solubility and low relative affinity for absorption onto soils. Consequently, much of the salt washed from salt piles or from applications to roads enters the groundwater or surface waters (Cheveron Chemical Company, 1991). Studies have shown that vegetation can decrease salt concentrations along roadways.

Containment during bridge maintenance is important to keep pollutants from falling directly into surface waters during bridge maintenance.

Section 6.1 describes these management practices. Section 6.2 summarizes the effectiveness and costs of the practices. Section 6.3 discusses the practices' effectiveness and basis for determining the effectiveness. Section 6.4 discusses the practices' cost and the basis for determining costs.

6.1 DESCRIPTION

6.1.1 Maintenance of Vegetation

Establish and Maintain Vegetation

Maintaining a vigorous vegetation along road right-of-ways provides two water quality benefits. Vegetation protects the area from erosion and it removes pollutants as discussed for vegetative filter strips and grassed swales in Section 5.0. Grass is an effective type of vegetative ground cover, however, it must be maintained.

Maintenance should include inspection and quick stabilization and reseeding of any eroding areas. The number of grass mowings per growing season should be minimized to increase the grass height and resistance to flow. However, the grass must be periodically mowed since at some height and flow depth the grass will lay flat which reduces the pollutant reduction capabilities. The optimum number of mowings should be determined locally based on plant species and local conditions. In addition, the grass cuttings should be left on the ground to reduce velocities and act as a mulch (Hartigan et al, 1989).

Sediments must also be removed from vegetative channels when the hydraulic capacity is no longer available.

Pesticide/Herbicide Use Management

Limiting the application of pesticides and herbicides reduces the amount of these pollutants entering the storm water runoff and, hence, coastal waters. The use of pesticides and herbicides by State Highway Agencies (SHA) are typically managed through controls on application and training. This has resulted in a low percent of total pollutant load being attributed to pesticides and herbicides. Therefore, the pesticide/herbicide programs being used by SHAs should be continued (Hartigan et al, 1989).

6.1.2 Street Cleaning

Street Sweeping

Street cleaning uses either mechanical, vacuum or regenerative air sweepers. Most street cleaning programs are designed to improve aesthetics. However, street cleaning programs can also provide water quality befits by removing pollutants from the street surface before they are washed into the storm sewer system or surface waters. Street cleaning is most effective at removing debris and large particles. It is less effective at removing fine particles (SWRPC, 1991) and may even loosen fine particles embedded in the street surface and actually increase the concentration of fine particles in the runoff water.

Street sweeping is not effective for highways, but may be effective for roads in urban areas.

Litter Control

Litter control programs and regulations are often established for their aesthetic and safety value. However, these programs reduce nonpoint source pollution by removing potential pollutant sources.

General Maintenance

General maintenance includes pot hole repairs and road-side repairs. Road repairs reduce nonpoint source pollution by removing potential pollutant sources.

6.1.3 Deicing Chemical Use Management

Protection of Salt Piles

There are numerous environmental impacts associated with improper storage of salt piles. These impacts include destroying vegetation, polluting groundwater, and increasing soil erosion. According to the Salt Institute, almost all environmental problems associated with deicing salt result from improper storage; therefore, salt piles should always be protected from the natural elements - rain and snow. A Rhode Island DOT study estimated that 20% of the salt in unprotected piles was washed into the storm water runoff (The Land Management Project, 1989).

An under-roof storage facility is the best way to protect salt; however, there are a variety of other building types available for salt storage. The main requirements needed for a successful storage facility are: the salt piles should always be covered with a roof or temporary covering material like tarpaulin, have an impervious surface for storage and handling areas, and provide containment for contaminated runoff.

Minimization of the Application of Deicing Salts

States should follow EPA's guidelines for application rates to reduce the amounts of deicing salts used. Some recommended guidelines are: apply salt in smaller increments based on changing traffic and weather conditions, apply salt before storms that are expected to produce heavy snowfalls, and coordinate the timing of plowing and chemical application, so the salt can break the snow-ice bond at the road surface before the road is plowed. In addition, personnel training and more accurate weather information can help minimize the use of deicing salts (Richardson, 1974).

Specially Equipped Salt Application Trucks

The trucks used to apply deicing salts can be equipped with ground-speed sensors which control the salt discharge rate according to truck speed.

Use of Alternative Deicing Materials

Several deicing materials are available as an alternative to salt. These materials include calcium magnesium acetate (CMA), calcium chloride ($CaCl_2$), and urea. Of these materials, CMA is generating the most attention because it may be environmentally safe. In addition, field tests of CMA, by various state transportation agencies, show that CMA can deice roadways as well as or better than road salt (Chevron Chemical Company, 1991). The major concern associated with CMA is that it costs 20 times more than salt by weight. However, because CMA does not contribute to corrosion of bridges and automobiles, its life-cycle cost may be less than salt. Conversely, there are new technologies available for protecting new automobiles and bridges from corrosion, so it is difficult to determine salt verses CMA's actual life-cycle cost.

Therefore, CMA use should be evaluated on a site-by-site basis based on economic and environmental impacts of road deicing. In environmentally sensitive areas, alternative deicers like CMA may be the best economic and environmental choice. Table 6-1 summarizes some advantages and disadvantages of using salt (NaCl), CMA, Ca Cl_2, or urea.

Grassed Swales and Vegetative Filter Strips

Grassed swales and vegetative filter strips can reduce the concentration of salt in the runoff. See Section 5.0 for information about these two management practices.

6.1.4 Containment During Bridge Maintenance

Contain Pollutants Generated During Bridge Maintenance

Pollutants generated during maintenance operations such as paint, rust and paint removal agents, and sand blast material should be captured before it falls into coastal waters. Suspended tarps, vacuums, or booms in water have been used to capture the waste materials.

6.2 SUMMARY TABLES

This section presents summary tables (Tables 6-2, and 6-3) for various management practices. These summary tables are based on the detailed cost and effectiveness data presented in the Appendix.

Table 6-2 summarizes the effectiveness and cost of the various operation and maintenance management practices for maintenance of vegetation, street cleaning, and bridge maintenance. Effectiveness was defined as the percent pollutant removal which 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 6-2.

Table 6-1. Deicing Materials

	ADVANTAGES	DISADVANTAGES
NaCl	• Works quickly when applied in solution • Least expensive material cost	• Very corrosive • Harmful to roadside vegetation, soils, and drinking water
$CaCl_2$	• Works at low temperatures • Works quickly (reaction with water is exothermic)	• Very corrosive • Harmful to roadside vegetation, soils, and drinking water
Urea	• Works at low temperatures similar to $CaCl_2$ • Acts to clean oils off the roads	• Harmful to roadside vegetation with frequent, heavy applications • Expensive material cost
CMA	• Corrosion inhibitor • Effectiveness similar to NaCl indicated by extensive research • Does not harm roadside vegetation or drinking water • Works in temperature range similar to NaCl	• Expensive material cost
(Source: Nottingham et al, 1983)		

TABLE 6-2. OPERATION AND MAINTENANCE MANAGEMENT PRACTICES EFFECTIVENESS AND COST SUMMARY

MANAGEMENT PRACTICE		% REMOVAL						COST
		TSS	TP	TN	COD	Pb	Zn	
MAINTAIN VEGETATION								Natural Succession Allowed To Occur - Ave: $100/ac/Year
For Sediment Control	Ave:	90	NA	NA	NA	NA	NA	Reported Range: $50-$200/ac/Year
	Reported Range:	50-100	NA	NA	NA	NA	NA	References: Schueler, 1987
	Probable Range:	80-100	-	-	-	-	-	
For Pollutant Removal	Ave:	60	40	40	50	50	50	Natural Succession Not Allowed To Occur - Ave: $800/ac/Year
	Reported Range	0-100	0-100	0-70	20-80	0-100	50-60	Reported Range: $700-$900/ac/Year
	Probable Range:	0-100	0-100	0-100	0-100	0-100	0-100	References:
PESTICIDE/HERBICIDE USE MANAGEMENT								Being Economically Used In Many States
	Ave:	NA						
	Reported Range:	NA						
	Probable Range:	Being Effectively Used in Many States						
STREET SWEEPING								Ave: $20/Curb Mile Reported Range: $10-$30/Curb Mile References:
Smooth Street, Frequent Cleaning (One or More Passes Per Week)	Ave:	20	NA	NA	5	25	NA	
	Reported Range:	20	NA	NA	0-10	5-35	NA	
	Probable Range:	20-50	-	-	0-10	20-50	10-30	
Infrequent Cleaning (One Pass Per Month or Less)	Ave:	NA	NA	NA	NA	5	NA	
	Reported Range:	NA	NA	NA	NA	0-10	NA	
	Probable Range:	0-20	-	-	-	0-20	0-10	
LITTER CONTROL								Being Economically Used In Many Areas
	Ave:	NA						
	Reported Range:	NA						
	Probable Range:	Being Effectively Used in Many Areas						

TABLE 6-2. OPERATION AND MAINTENANCE MANAGEMENT PRACTICES EFFECTIVENESS AND COST SUMMARY (Continued)

MANAGEMENT PRACTICE	% REMOVAL						COST
	TSS	TP	TN	COD	Pb	Zn	
GENERAL MAINTENANCE							Being Economically Used In Many Areas
Ave:	NA						
Reported Range:	NA						
Probable Range:	Being Effectively Used in Many Areas						
CONTAIN POLLUTANTS GENERATED DURING BRIDGE MAINTENANCE							Varies With Method of Containment Used
Ave:	NA						
Reported Range:	NA						
Probable Range:	50-100%*						

*measured as reduction of all pollutants NA: Not Applicable

Table 6-3 summarizes the effectiveness and cost of deicing chemical use management practices. This information is reported as percent of salt removal.

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, Tables 6-2 and 6-3 present 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 6.3, and the references considered in developing the 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 Tables 6-2 and 6-3. 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).

Tables 6-2 and 6-3 present annual maintenance cost information. In these tables, the cost information is annualized so that comparisons can be made from one practice to another. 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 maintenance contracts.

TABLE 6-3. OPERATION AND MAINTENANCE MANAGEMENT PRACTICES EFFECTIVENESS AND COST SUMMARY

MANAGEMENT PRACTICE	% REMOVAL SALT (NaCl)	COST
PROTECTION OF SALT PILES		For Salt Storage Building-
Ave.:	NA	Ave.: $30/ton salt
Reported Range:	NA	Reported Range: $10-70/ton salt
Probable Range:	90-100	
MINIMIZATION OF APPLICATION OF DEICING SALTS		Being Economically Used in Many Areas
Ave.:	NA	
Reported Range:	NA	
Probable Range:	Deicing salts that are not applied to roads will not enter runoff	
SPECIALLY EQUIPPED SALT APPLICATION TRUCKS		For Spread Rate Control on Truck -
Ave.:	NA	Ave.: $6,000/truck
Reported Range:	NA	Reported Range: $6,000/truck
Probable Range:	Deicing salts that are not applied to roads will not enter runoff	
USE OF ALTERNATIVE DEICING MATERIALS		CMA -
Ave.:	NA	Ave.: $650/ton
Reported Range:	NA	Reported Range: $650/ton
Probable Range:	Deicing salts that are not applied to roads will not enter runoff	(Note: Cost of Salt $40/ton)

6.3 EFFECTIVENESS

The following is a discussion of the factors that influence the effectiveness of the various management practices shown in Tables 6-2 and 6-3. The data analyzed to draw the following effectiveness conclusions are presented in Appendix A. See Section 6.2 for a discussion of the effectiveness information.

6.3.1 Maintenance of Vegetation

Establish and Maintain Vegetation

Established vegetation is very effective in reducing erosion. Established vegetation can reduce total suspended solid loads by 50-100% from pre-establishment loads (Woodward-Clyde, 1992).

Vegetation can also provide pollutant reduction as discussed for vegetative filter strips and grassed swales in Section 5.0.

Pesticide/Herbicide Use Management

Existing pesticide/herbicide control programs implemented by State Highway Agencies (SHAs) appear to be effective since the percent of total pollutant loads attributed to pesticides and herbicides is low (Hartigan et al, 1989).

6.3.2 Street Cleaning

Street Sweeping

The effectiveness of street cleaning is dependant on many site specific variables including:

- rainfall patterns
- season
- pollutant accumulation
    - a. traffic density
    - b. dry deposition from local industrial and commercial activities
- equipment access (i.e., absence of parked vehicles)

- frequency of cleaning
- operator proficiency
- equipment type and condition

Nine references contained information on the removal efficiency of street cleaning. However, only four of these references reported the percent pollutant removal from street surface. These rates will typically be higher than the percent pollutant removal from runoff because some of the pollutant loads on the streets would never be taken-up by the runoff.

As part of NURP, 5 projects studied 10 sites. The conclusion from the NURP study was that based on statistical testing, no significant reductions in EMC are realized by street sweeping (EPA, 1983). However, a large database is required to actually identify possible effects. The report concluded that if there are pollutant reductions from street cleaning, they are not large (i.e., greater than 50%).

Street cleaning studies in Toronto, Castro Valley, CA and San Jose, CA indicate that street cleaning on smooth streets done frequently can reduce total solids and heavy metal concentrations in runoff. Only one study mentioned organics and nutrients and concluded that street cleaning is not effective for these pollutants.

Litter Control

Litter control reduces nonpoint source pollution by removing potential pollutant sources.

General Maintenance

General maintenance also reduces nonpoint source pollution by removing potential pollutant sources.

6.3.3 Deicing Chemical Use Management

Protection of Salt Piles

A properly designed, constructed and maintained salt storage facility should be able to eliminate salt-laden runoff from leaving the site. EPA's salt and storage guidelines should be implemented to insure that the storage facility is structurally and environmentally safe. A Rhode Island DOT study estimated that 20% of salt in unprotected piles was washed into storm water runoff. Some of these guidelines are listed below:

- Storages should be large enough to hold the maximum amount of chemicals without overflowing.
- Sufficient vertical and horizontal clearance should be provided so delivery trucks can unload easily without damaging the structure.
- The storage should be sturdy enough to handle rough usage.
- Good lighting should be provided for night time operations.

Minimization of the Application of Deicing Salts, Specially Equipped Salt Application Trucks, and Use of Alternative Deicing Materials

It is not possible to quantify the reduced pollutant loadings that will result from the use of these management practices. However, if these management practices are implemented, less salt will be applied to the roads, and therefore, less will enter coastal waters.

6.3.4 Containment During Bridge Maintenance

Contain Pollutants Generated During Bridge Maintenance

Although it is difficult to contain 100% of the pollutants, most pollutants should be contained with suspended tarps, vacuums, or booms in the water.

6.4 COST

The cost of the management practices varies greatly and is dependent upon factors such as availability and proximity of materials, time of year and labor rates. The costs presented in this document are a summary of the costs found in published documents. These costs are presented to give planners an idea of the cost of a practice relative to another but are not recommended for use in estimating and 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 were presented in Tables 6-2 and 6-3 of this report. The following is a discussion of the factors that influence the costs that can be expected in implementing various management practices.

6.4.1 Maintenance of Vegetation

Establish and Maintain Vegetation

The cost to maintain vegetation will partially depend on if natural succession is allowed to occur.

Pesticide/Herbicide Use Management

Many State Highway Agencies have effective pesticide/herbicide programs in place.

6.4.2 Street Cleaning

Street Cleaning

One source was obtained that included the operating cost per curb-mile for 5 sites. These costs included labor, equipment depreciation, fuel, maintenance/materials, overhead and disposal.

Litter Control

Many areas have effective litter control programs in place such as the Adopt-A-Highway Program.

General Maintenance

No costs were found in the literature.

6.4.3 Deicing Chemical Use Management

Protection of Salt Piles

One reference was found that gave the construction cost of 17 different constructed salt storage buildings.

Minimization of Application of Deicing Salts

No costs were found in the literature, however, the average cost/ton of salt is \$25 to \$50. Thus, reducing the amount applied would result in a savings of \$1.25 to \$2.50 per 100 pounds.

Specially Equipped Application Trucks

One reference was found for this cost. This cost includes equipment only and not calibration or maintenance costs.

Use of Alternative Deicing Materials

Two references were found which gave the cost of alternative deicing materials. In addition, two references compared the economic cost of road salt and corrosion caused by salt, versus the economic cost of deicing salt alternatives, which were not as harmful to the environment, infrastructure, and automobiles (Foster, 1990 and Chevron, 1991).

6.4.4 Containment During Bridge Maintenance

Contain Pollutants Generated During Bridge Maintenance

Although the cost of containing pollutants during bridge maintenance will depend upon the containment method used, one reference estimated the cost of containing paint chips with a tarpaulin and then disposing the paint chips in a properly designed landfill to be approximately $7,000 (Heller et al, 1992).

The following section presents management practice options for Roads, Highways and Bridges. The management practices listed are mainly for illustrative purposes and they are not all-inclusive. State or local laws, rules, or standards may also require the use of additional practices from those listed in this section.

7.1 PLANNING AND DESIGN PRACTICES FOR ROADS AND HIGHWAYS

In the initial planning and design phase, roads and highways should be located away from coastal shorelines, critical habitat, wetlands, riparian areas, drainage channels and streams. Potential erosion, sedimentation, and pollution problems should be considered. These practices can be used for all new roads and highways, including residential streets.

The best time to address control of NPS runoff pollution from roads and highways is during the planning process. Locating roads and highways away from critical areas, and receiving waters is the most suitable means for controlling runoff pollution from reaching the receiving waters. However, when roads and highways must be located near receiving waters, then effective controls should be considered to treat the runoff as necessary to mitigate any potential NPS pollution.

The AASHTO Highway Subcommittee on Design guidance presented in "A Guide for Transportation Landscape and Environmental Design" (AASHTO, 1991) stresses careful project planning early in the design process that can often prevent the displacement of sensitive land or water areas. In addition, the FHWA's Federal-Aid Policy Guide (FHWA, 1991) indicates that it is the policy of the FHWA that Federal-aid highways and highways constructed under the direct supervision of FHWA shall be located, designed, constructed and operated according to standards that will minimize erosion and sediment damage to the highway and adjacent properties and abate pollution of surface and ground water resources.

Practices

The following practices listed below can be used. Descriptions of some of these practices can be found in Section 3.0 of this document. Descriptions of the structural practices can be found in Section 5.0 of this document.

- Provide design details for permanent erosion and sediment controls (e.g. vegetative buffer strips, grassed swales, pond systems, infiltration systems, constructed stormwater wetlands, and energy dissipators and velocity controls) during the planning phase of roads, highways and bridges. (See American Association of State Highway Transportation Officials (AASHTO), 1991(a); and Hartigan et. al., 1989)

- Avoid marshes, bogs, and other low lying lands subject to flooding. All wetlands that are within the highway corridor and subject to removal should be mitigated. (See AASHTO, 1991(b); and Campbell, 1988)

- Avoid locations requiring excessive cut and fill. (See AASHTO, 1991(b) and Campbell, 1988)

- Avoid placing highways at right angles to a series of natural drainage channels. See AASHTO, 1991(b))

- Avoid locations subject to subsidence, sink holes, landslides, rock outcroppings, and highly erodible soils. (See AASHTO, 1991(b); and Campbell, 1988)

- Select locations on high ground.

- Size rights-of-way to include space for siting runoff pollution control structures as appropriate. (See Hartigan et. al, 1989; and AASHTO, 1991(a))

- Design residential roads and streets in accordance with local subdivision regulations, zoning ordinances, and other local site planning requirements.

- Select the most economic and environmentally sound route location. (See AASHTO, 1991(b) and Campbell, 1989)

- Use interactive computer models to determine stormwater runoff impacts with all proposed route corridors. (See Driscoll et. al., 1990)

- Prepare an environmental impact assessment. (See AASHTO, 1991(b))

- Coordinate the design of pollution controls with appropriate State and Federal environmental agencies.

- Prepare official mapping to show location of proposed highway corridors.

Effectiveness and Cost

The most economical time to consider erosion/sediment and runoff pollution control is during the planning and design phase of roads and highways. It is much more costly to correct NPS pollution problems after a road or highway has already been built. The most effective and often economical control is to locate the roads as far away from receiving waters and critical areas as possible. However, some portions of roads and highways cannot be located where NPS pollution does not pose a threat to receiving waters. In these cases, interactive computer models designed to run on a PC (e.g. FHWA's model (Driscoll et al., 1990)) can be used to examine the impacts of the proposed road or highway on receiving waters. If controls are needed, then several economical and effective practices (e.g. vegetated buffer strips, grassed swales, pond systems, etc.) can be considered and used to treat runoff. Effectiveness and cost information for these practices are presented in Section 5.0.

7.2 PLANNING AND DESIGN PRACTICES FOR BRIDGES

New bridge structures should be sited and designed in such a manner that shellfish beds, fisheries, wetlands, critical habitat areas, and other sensitive ecosystems are protected. Bridge waterway crossings are preferred to causeway designs. These practices can be used for new bridge structures that cannot avoid locations in areas with identified sensitive ecosystems such as oyster beds, clam harvest areas, specialized fisheries, and critical flora/fauna habitats. It should be noted that some bridges may also be subject to U.S. Coast Guard approval by

Nationwide Permit No. 15, issued by the U.S. Army Corps of Engineers (USACE) under Section 404 of the Clean Water Act.

Research has shown that bridge construction in coastal areas may cause significant erosion and sedimentation resulting in the loss of wetlands and riparian vegetation and runoff from bridges may deliver considerable loadings of heavy metals, hydrocarbons, toxic substances and deicing materials to receiving waters, as a result of direct delivery through scupper drains with no overland buffering (Irwin and Losey, 1978; and McKenzie and Irwin, 1983). Bridge maintenance can also contribute heavy loads of lead, rust, paint, particulates, solvents, and cleaners. States such as South Carolina and Florida have been actively working to mitigate the pollution effects from bridge runoff. Guidelines have also been prepared for the management of runoff from bridges (Wanielista et. al, 1980).

Practices

The practices listed below can be used. Descriptions of some of these practices can be found in AASHTO, 1989; U.S. Coast Guard, 1983; and Section 3.0 of this document.

- Coordinate design with FHWA, USCG, USACE, and other State and Federal agencies as appropriate.
- Review environmental impact assessment to insure environmental concerns are met.
- Avoid locations requiring numerous river crossings.
- Direct pollutant loadings away from bridge decks by diverting runoff waters to land for treatment.
- Avoid the use of scupper drains on bridges crossing sensitive ecosystems.
- Locate bridges to avoid sensitive ecosystems.

Effectiveness and Cost

The costs of implementing the above practices must be weighted against the economic benefits of protecting commercial fisheries and shellfish harvesting areas from runoff waters potentially containing road surface containments including deicing salts and abrasives, heavy metals, accidental toxic spills, and automotive fluid leakage. To protect these sensitive areas, management practices such as minimizing the use of scupper drains and diverting runoff waters to land for treatment in detention ponds and infiltration systems should be used to mitigate the pollutant loadings. See Section 5.0 for costs and effectiveness data of ponds, wetlands, and filtration devices.

7.3 CONSTRUCTION PROJECT PRACTICES

Practices should be used at all road, highway, and bridge construction projects in order to minimize the detachment and mobilization of sediment, and control/retain sediment onsite.

Erosion and sedimentation from road, highway, and bridge construction, as well as unstabilized cut and fill areas, can result in serious environmental impacts on receiving waters. Additionally, FHWA's Federal Aid Policy Guide (FHWA, 1991) also requires that erosion and sediment damage from the construction of Federal-aid highways and highways under the direct supervision of FHWA be minimized.

Practices

The practices listed below can be used. Guidance on these and other erosion and sediment control practices for road and highway projects can also be found in AASHTO, 1990; FHWA, 1985; and in Section 4.0 of this document.

- Write erosion and sediment control requirements into plans, specifications, and estimates for Federal aid construction contracts, for highways and bridges (FHWA, 1991).

- Coordinate erosion and sediment controls with FHWA and AASHTO guidelines.

- Install permanent erosion and sediment control structures at the earliest practicable time in the construction phase.

- After construction, temporary control structures are to be removed and areas restored. Sediments will be disposed of in accordance with State and Federal regulations.

- Coordinate temporary erosion and sediment control structures with permanent practices.

Effectiveness and Cost

Detailed information on the effectiveness and cost of erosion and sediment control management practices can be found in Urban BMP Cost and Effectiveness Summary Data for 6217(g) Guidance - Erosion and Sediment Control During Construction (Woodward-Clyde, 1993).

7.4 CONSTRUCTION SITE CHEMICAL CONTROL PRACTICES

Practices should be used at all roads, hoghway, and bridge construction projects in order to minimize toxic and nutrient loadings by reducing the generation and migration of toxic substances and avoiding excess application of nutrients.

Toxic substances and nutrients tend to bind to fine soil particles, and control of sediments in most cases, can limit the loadings of these pollutants. However, some substances and nutrients (e.g. nitrogen) are very soluble, and excess applications or spills during construction can pose significant environmental impacts.

Practices

The practices listed below can be used.

- Limit machinery maintenance to areas designated and equipped for this activity.

- Limit machinery site access and establish machinery staging pads.

- Require proper handling and storage of fuels, oils, fertilizers, and other potential NPS pollutants.

- Minimize runoff entering and leaving the site through perimeter and onsite sediment controls.

- Inspect and maintain erosion and sediment control practices (both onsite and perimeter) until disturbed areas are permanently stabilized.

- Divert and convey offsite runoff around disturbed soils and steep slopes to stable areas in order to prevent transport of pollutants offsite.

- Locate large graded areas on the most level portion of the site and avoid the development of steep vegetated slopes.

Effectiveness and Cost

Detailed information on the effectiveness and cost of erosion and sediment control management practices can be found in Urban BMP Cost and Effectiveness Summary Data for 6217(g) Guidance - Erosion and Sediment Control During Construction (Woodward-Clyde, 1993).

7.5 OPERATION AND MAINTENANCE PREVENTIVE PRACTICES

Effective operation and maintenance programs can reduce NPS pollution from erosion of poorly vegetated areas; pesticides and nutrients; litter and debris; deicing materials; and debris and toxic substances from bridge maintenance. The U.S. Coast Guard and states such as Virginia require that loadings of paint chips, solvents, and particulates be controlled during bridge maintenance. Additionally, EPA, FHWA, and the Salt Institute encourage the minimization of the application of road salts.

Practices

The practices listed below can be used for effective operation and maintenance of roads. Descriptions of some of these practices can be found in Section 6.0 of this document.

- Establish pesticide/herbicide use and nutrient management programs. (See Hartigan et al, 1989)

- Restrict herbicide and pesticide use in highway rights-of-way to applicators certified under FIFRA to assure safe and effective application.

- The use of chemicals such as soil stabilizers, dust palliatives, sterilants, and growth inhibitors should be limited to the best estimate of optimum application rates. All feasible measures should be taken to avoid excess application and consequent intrusion of such chemicals into surface runoff. (See Hartigan et al, 1989; FHWA, 1991)

- Sweep, vacuum, and wash residential/urban streets and parking lots. (See Pitt, 1986; EPA, 1982; Puget Sound Water Quality Authority, 1989; and City of Austin, 1988)

- Collect and remove road debris.

- Cover salt storage piles. (See Salt Institute, 1987)

- Minimize and regulate the application of deicing salts. (See Salt Institute, 1991)

- Use specially equipped salt application trucks. (See Salt Institute, 1991)

- Use alternative deicing materials, besides salt, where feasible. (See Transportation Research Board, 1991)

- Organize education programs.

- Encourage litter and debris control management.

- Provide general maintenance such as pothole repair and sealing cracks.

- Inspect and maintain stormwater management and pollution control facilities. (See Yousef, et al, 1991)

- Accumulated sediment from stormwater management and pollution control facilities, and any wastes generated during maintenance, should be disposed of in accordance with appropriate local, State, and Federal regulations. (See Yousef et al, 1991)

- Reduce the delivery of pollutants used or generated during bridge maintenance (e.g., paint, solvents, scrapings) from entering receiving waters (e.g., suspended tarps, vacuums, or booms). (See AASHTO, 1987)

Effectiveness and Cost

Preventive maintenance is a time-proven cost-effective management approach. Regularly scheduled maintenance to repair potholes, restore vegetation, and frequent sweeping and vacuuming of urban streets have effective results in pollution control. Litter control and clean-up practices are a low cost means for eliminating causes of pollution as are the proper handling of fertilizers, pesticides, and other toxic materials including deicing salts and abrasives. Tables 6-2 and 6-3 present summary information on the cost and effectiveness of operation and maintenance practices for roads, highways, and bridges. Many states and communities are already implementing several of these practices within their budget. As seen in Table 6-3, the use of road salt alternatives such as CMA can be very costly. However, some researchers have indicated that reductions in corrosion of infrastructure, damage to roadside vegetation, and the quantity of material that needs to be applied may offset the higher cost of CMA. Use of road salt minimization practices such as salt storage protection and special salt spreading equipment reduces the amount of salt that a state or community must purchase. Consequently, implementation of these practices can pay for themselves through savings in salt purchasing costs. Similar programs such as nutrient and pesticide management can also lead to decreased expenditures for materials. Detailed cost and effectiveness data for these practices are presented in Section 6.0.

7.6 OPERATION AND MAINTENANCE VEGETATIVE PRACTICES

Vegetated areas and stormwater management systems along roads, highways and bridges should be maintained, and cut and fill areas should be stabilized. Substantial amounts of eroded material can be generated from poorly vegetated areas and unstable cut and fill areas. The Federal-Aid Policy Guide (FHWA, 1991) that indicates erosion control measures should be emphasized by the maintenance departments and the AASHTO "Model Drainage Manual" (AASHTO, 1991) that indicates a thorough maintenance and follow-up program should be implemented.

Practices

The practices listed below can be used.

- Seed and fertilize; seed and mulch; and/or sod damaged vegetated areas and slopes.
- Construct retaining walls.
- Develop an inspection program to ensure all areas are stabilized.
- Use energy dissipators and velocity controls to reduce runoff velocity and erosion.
- Reduce steepness of side slopes.

Effectiveness and Cost

The costs associated with erosion and sediment loss are significant. The practices listed for the maintenance of roads, highways, and bridges are effective preventive approaches to erosion and sediment control. See Sections 4.0 and 6.0 for information on cost and effectiveness.

7.7 RETROFIT PRACTICES

Retrofitting control structures within rights-of-way or adjacent land areas can reduce pollutant loadings from existing roads, highways and bridges. Older and poorly located roads, highways and bridges may be generating significant NPS pollution loads that could severely impact receiving waters and their tributaries. Studies by many agencies and states such as FHWA (Driscoll et al, 1989 and 1990; and Gupta, 1981), EPA (Pitt and Amy, 1973; and Sartor and Boyd, 1972), the State of Washington (Portele et al, 1982) and Pennsylvania (Spotts, 1989) have quantified these loads as well as their impacts.

Practices

The practices listed below can be used. Descriptions of structural stormwater management and pollution control facilities can be found in Section 5.0 of this document.

- Locate runoff treatment facilities within existing rights-of-way or in medians and interchange loops.
- Develop multiple use treatment facilities on adjacent lands (e.g. parks and golf courses).
- Acquire additional land for locating treatment facilities.
- Use underground storage.

Effectiveness and Cost

Cost and effectiveness data for structural stormwater management and pollution control facilities are presented in Section 5.0. Installing these facilities on existing roads, highways and bridges can be more costly because of the need to purchase additional land. However, multiple-use facilities on adjacent lands can offset this cost. As with other sections of this document, the costs of loss of habitat, fisheries, and recreational areas must be weighed against the cost of retrofitting existing roads, highways and bridges to control NPS pollutant loads.

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APPENDICES

APPENDIX A

EFFICIENCY DATA

MANAGEMENT PRACTICE'S REMOVAL 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**

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 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	LOCATION	WATERSHED 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 / Cold Weather Melt Water / Weighted Total Annual 90 13 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 (%)									STUDY TYPE	REFERENCE
					TSS	TP	TKN	Pb	Zn	Cr	Ni	Cu	OTHER		
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%		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: 2-11% TOC: 29-76%	4 storms monitored	
													Nox: -28 to -143%		
	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	WATER-SHED 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**

DESCRIPTION	LOCATION	DRAINAGE AREA	LOCATION	REMOVAL EFFICIENCY (%)									STUDY TYPE	REFERENCE
				TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER		
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: Asphalt in good condition Asphalt in poor condition Rough oil and screenings surface	San Jose, CA	NA						30-60 40 5-12	30-60 40 5-12	30-60 40 5-12	TS: 30-60 TKN: 30-60 OP: 30-60 TS: 40 TKN: 40 OP: 40 TS: 5-12 TKN: 5-12 OP: 5-12	In-situ Removal efficiencies for COD, TKN, Pb, OP, Zn, Cr, Cu, Cd approx equal to TS	Pitt, 1979 cited in Finnemore, 1982

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		
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) | One Pass (%) | Two Passes (%) | Three Passes (%) 60 | 41.0 | 74.0 | 94.8 30 | 60.5 | 87.9 | 97.6 14 | 66.0 | 92.1 | 98.4 7 | 75.5 | 95.0 | 99.0 1 | 79.4 | 96.4 | 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)	[illegible]	(-10.0)	
	2	London Commons	VA	27	11.4	0.22	A: 29.0 B: 74.0	40.0 56.0		25.0 60.0		17.0 41.0	39.0 25.0	24.0 40.0	
	3	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

able 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	WATERSHED AREA (Acres)	TREATMENT 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 I. LITERATURE RESEARCHED TO INVESTIGATE PERFORMANCE CHARACTERISTICS OF WETLANDS

Study		Location	Name / I. D.	Detention Pond /Wetland	Constructed /Natural	Wetland Classification
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 1986	Orange County	detention pond *	65	60	19		17	60	-17	33	57	76	7	
	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. 1986	Lake Apopka	reservoirs				4.8		57.5	68.1	60.9		75.1		
		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 1985	Fish Lake	wetland/pond	95	78	-20		36	0		37		28		
	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 1988	McCarrons Wetland	detention pond *	91	95	85	88			60	78		57	90	
	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		
Melorin 1986	DUST Marsh													
	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. 1981	Angora Creek	wetland	54			-20		20	50	5				
	Tallac Lagoon	wetland	36			-88		33	35	-120				
Scherger and Davis 1982	Pittsfield-Ann Arbor	detention pond *	39			14				23				
	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. 1989	Tanners Lake	detention pond *	63	50	5	7			1	7	20	-14		
	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. 1990	B31	wetland	14						.4	-2				
	PC12	wetland	56						20	-2				
Rushton and Dye 1990	Tampa Office Pond	wetland	64				-3.7			55	65			
Hey and Barrett 1991	Des Plaines River Wetland													
	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

Study	System Name	System Type	Lead total	Lead dissolved	Zinc total	Zinc dissolved	Copper total	Copper dissolved	Cadmium total	Cadmium dissolved	Nickel total	Nickel dissolved	Chromium total	Chromium dissolved	Oil and Grease
Martin and Smoot	Orange County	detention pond *	39	29	15	-17									
1986	Treatment System	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	Fish Lake	wetland/pond													
1985	Lake Elmo	wetland													
	Lake Riley	wetland													
	Spring Lake	wetland													
Wotzka and Obert	McCarrons Wetland	detention pond *	85												
1988	Treatment System	wetland *	68												
		system	90												
Hickok et al. 1977	Wayzata Wetland	wetland	94		82		80		67						
Barten 1987	Clear Lake	wetland													
Meiorin	DUST Marsh														
1986	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.	Angora Creek	wetland													
1981	Tallac Lagoon	wetland													
Scherger and Davis	Pittsfield-Ann Arbor	detention pond *	61												0
1982	Swift Run	wetland	83												0
ABAG 1979	Palo Alto Marsh	wetland													
Jolly 1990	Long Lake Wetland-Pond Treatment System	entire system													
Oberts et al.	Tanners Lake	detention pond *	59												
1989	McKnight Lake	detention ponds *	63												
	Lake Ridge	wetland	52												
	Carver Ravine	wetland-pond system	6												
Reinelt et al.	B31	wetland													
1990	PC12	wetland													
Rushton and Dye 1990	Tampa Office Pond	wetland			34										
Hey and Barrett	Des Plaines River Wetland														
1991	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.
Ersy 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
1985		commercial	5										discrete channelized flow.
		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
1988	Treatment System			wetland	6.2		1.0%					diffuse	dissipate surface water energy.
				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
1977		commercial											existed regardless of a single discrete inlet.
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
1986		agriculture	7	wetland B	6		0.2%						due to long and narrow wetland basins.
				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
1981	Tallac Lagoon			wetland	NA	2781	NA	8.68	NA	NA	NA	diffuse	is large enough to force sheet flow through the meadowlands.
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	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.
1979		commercial	12										• Channelized flow exist until the tide increases causing
		open	26										the surrounding marsh to become inundated.
Jolly	Long Lake Wetland-Pond	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
1990	Treatment System												strip, constructed wetland, and deep pond.
Oberts et al.	Tanners Lake	residential	NA	pond	0.07	1134	negligible	NA	0.1	NA	3.0	discrete	• Monitoring occurred during a dry period.
1989	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	
Reinelt et al.	B3I	urbanized	NA	wetland	4.9	461.7	1.1%	1.5	0.03-0.43	3.3	NA	discrete	• Storm flows reduce detention times.
1990	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	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
1990													high water; leak and breach problems occurred during study.
Hey and Barrett	Des Plaines River Wetland	NA	NA	EWA 3	5.6	-	-	5	NA	NA	1	discrete	• Water is pumped to the system from the river (drainage area
1991	Demonstration Project	NA	NA	EWA 4	5.6	-	-	0.6	NA	NA	1	discrete	of 210 square miles) for 20 hours per week.
		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 817 cf
(0.23 in. runoff) (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

puted 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

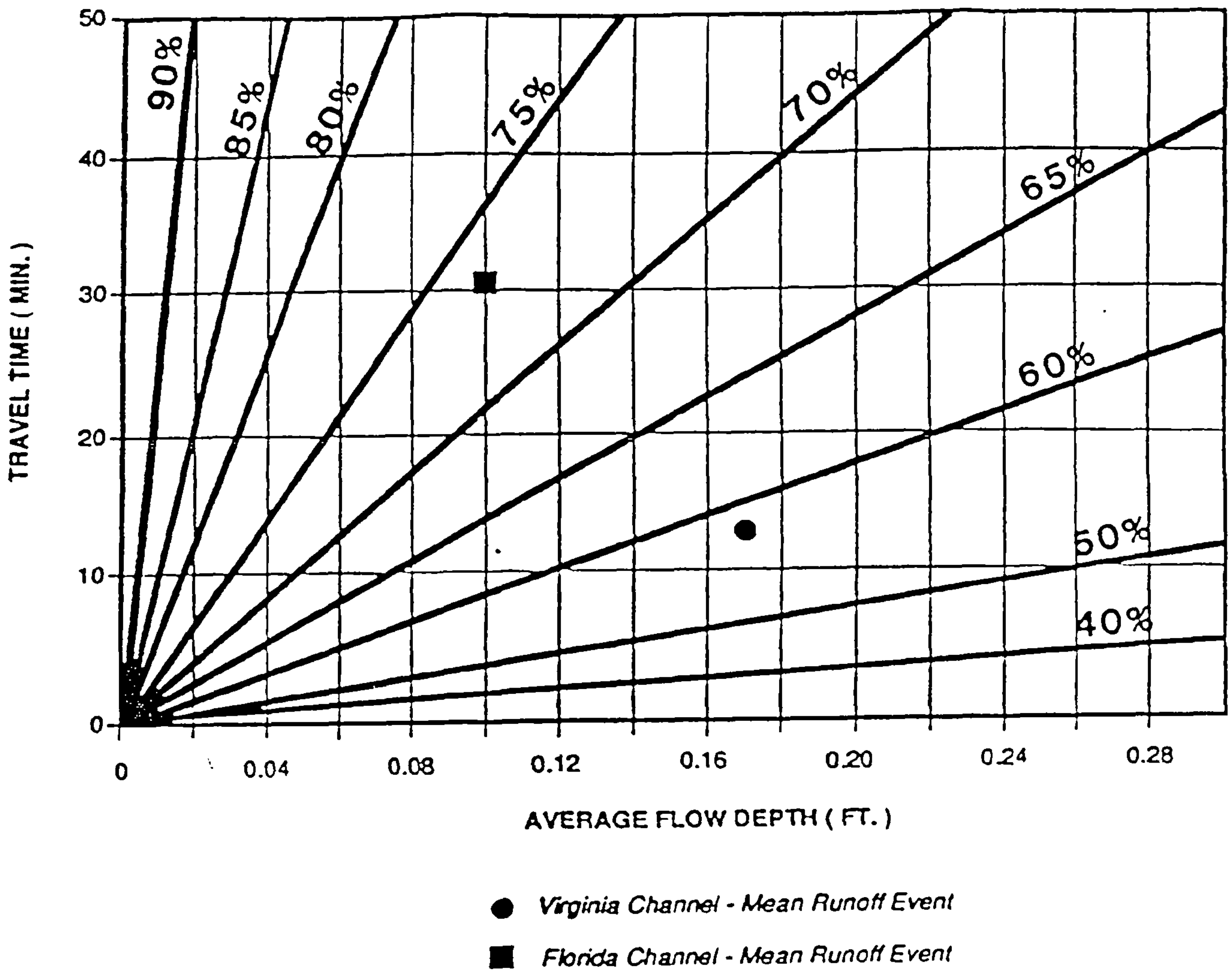
Area = 1 ac
Rv = 0.5
Volume = 90% ave runoff 1053 cf
(0.29 in. runoff) (1 ac * 0.50 * 0.64 in * 90%)

QR	VR
166.98	1161.6

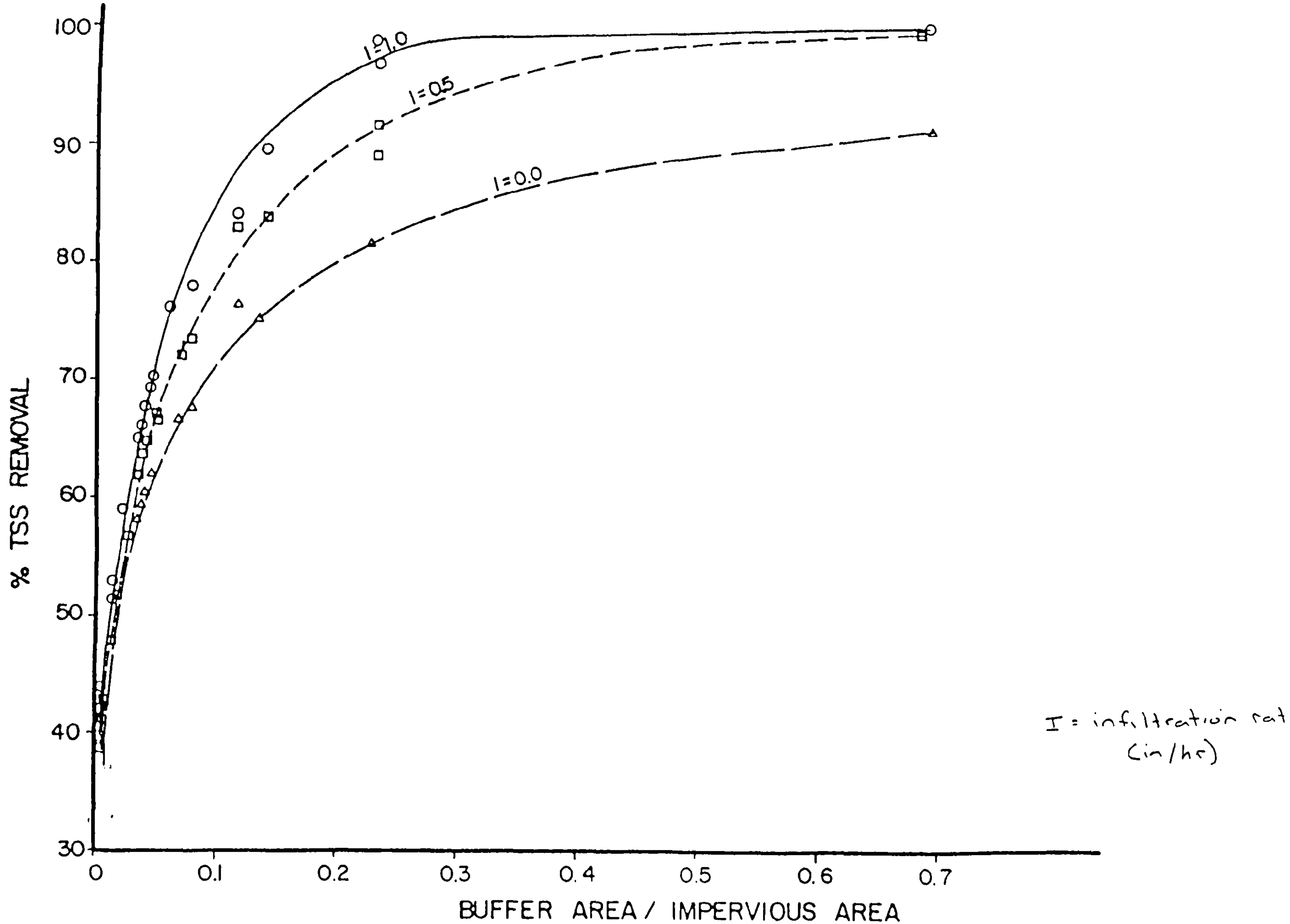
*** Perc. Rate (in/hr)	*** Height (ft)	Surf. Area (sq. ft.)	QT	QT/QR	VB	VB/VR	E	*Fig 4* VE/VR	*Fig 1* % FLOW	*Fig 3 % VOL	% REMOVAL
8.27	2	526.4	362.7	2.17	1052.7	0.9	44.7	0.9	81	58.0	92.0
8.27	5	210.5	145.1	0.87	1052.7	0.9	17.9	0.9	51	58.0	79.4
8.27	8	131.6	90.7	0.54	1052.7	0.9	11.2	0.9	35	58.0	72.7
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 B

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

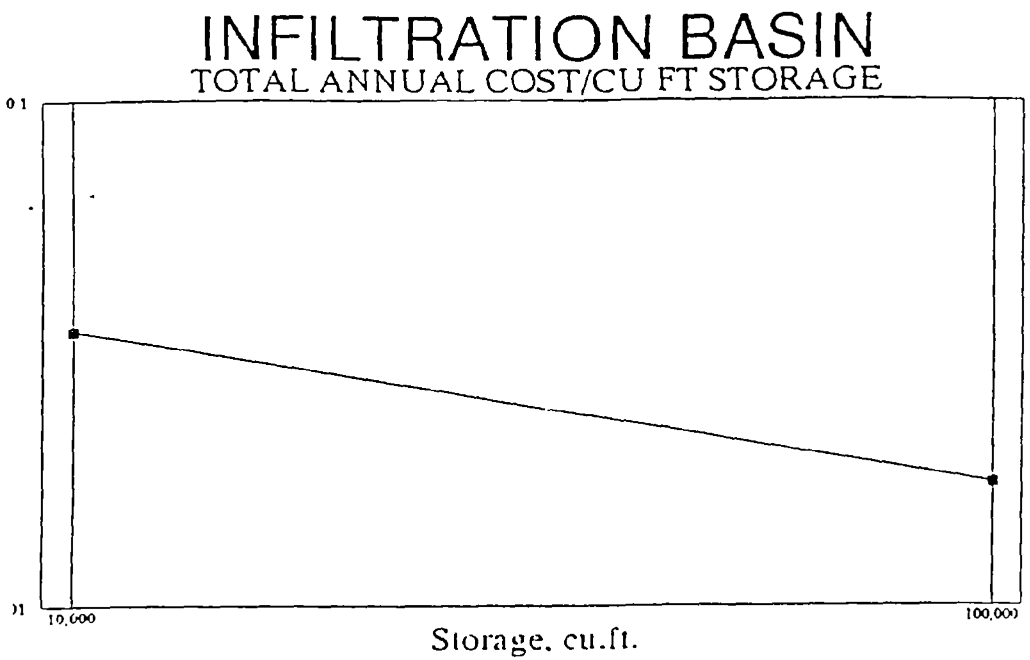
INFILTRATION BASIN– Oconomowoc, Wisconsin (estimated for 3 foot deep infiltration basin)

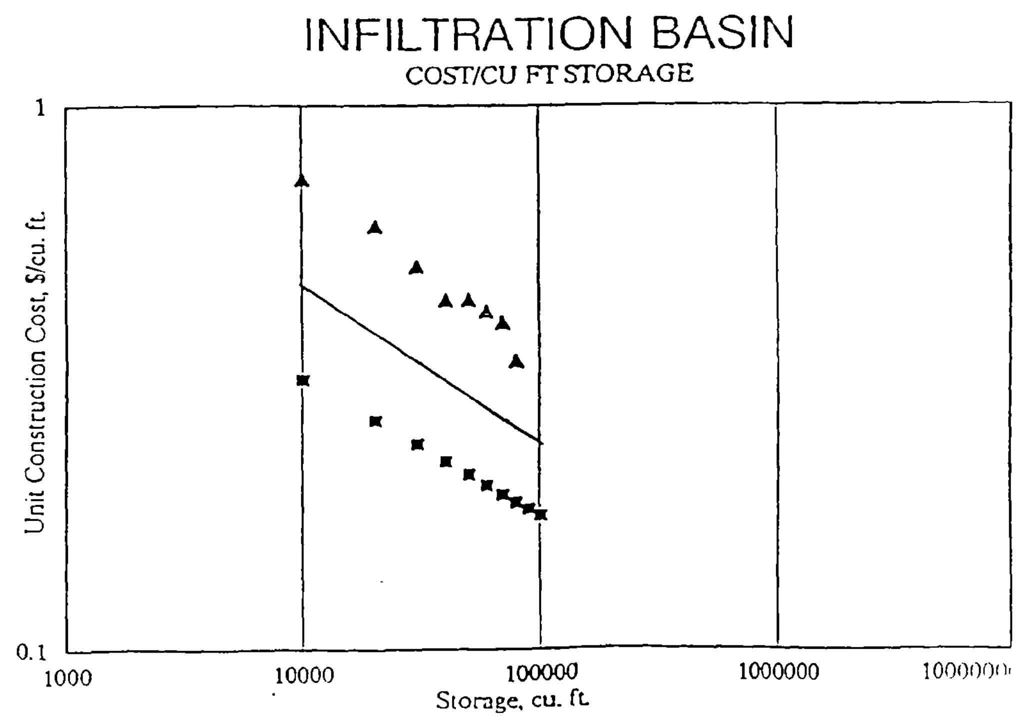
Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)
NA	NA	1.18	13%

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

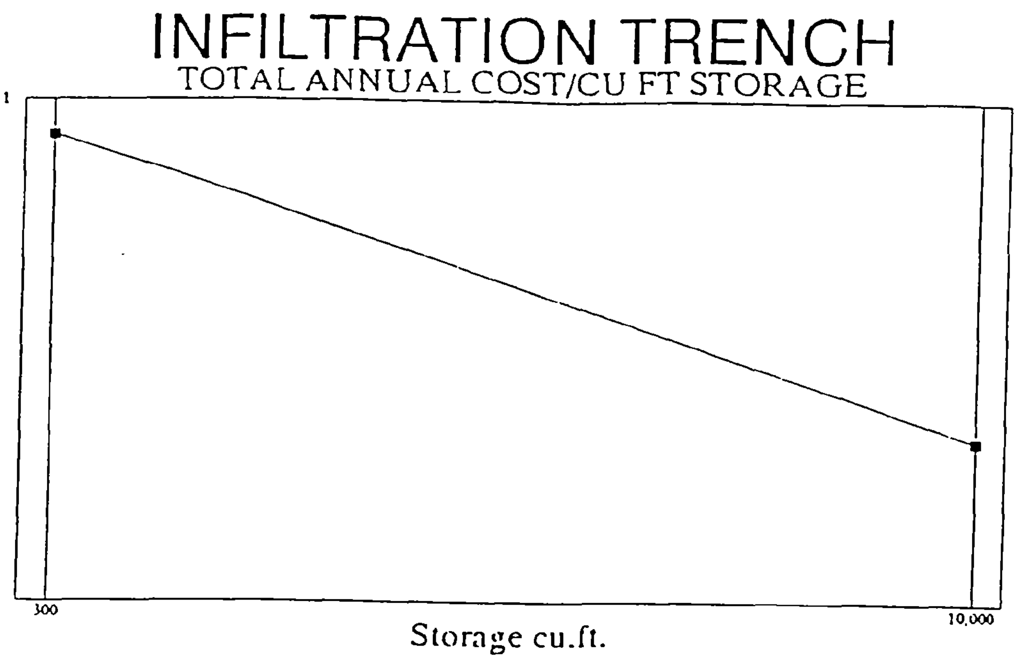
Storage Volume (cu. ft.)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Annual Maint. Cost (% capital cost)	Comments
198	1,815	9.17	7%	5'x3'x33'
304	1,805	5.94	5%	5'x8'x19'
300	2,750	9.17	7%	5'x3'x50
2004	12,525	6.25	7%	10'x3'x167'
2016	9,450	4.69	5%	10'x8'x63'
3996	21,756	5.44	6%	15'x3'x222'
3984	16,600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

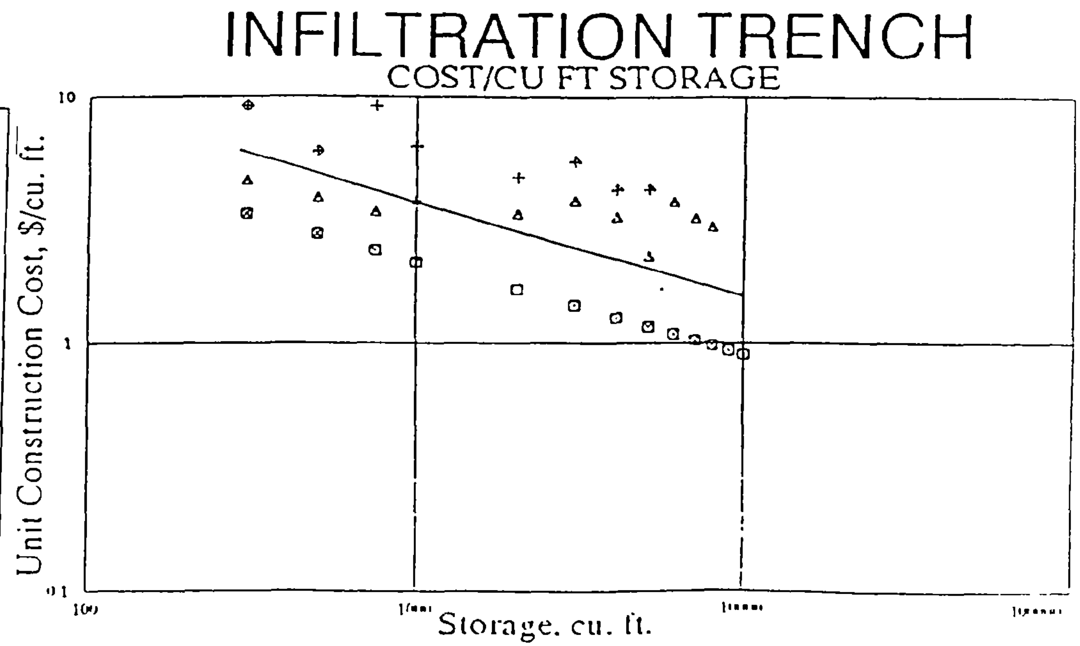
INFILTRATION TRENCH – (based on equation); Kuo, et.al., 1988

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)
Hydroseeding	1–2	2,024	NA
Hydroseeding	2–5	1,793	NA
Hydroseeding	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.

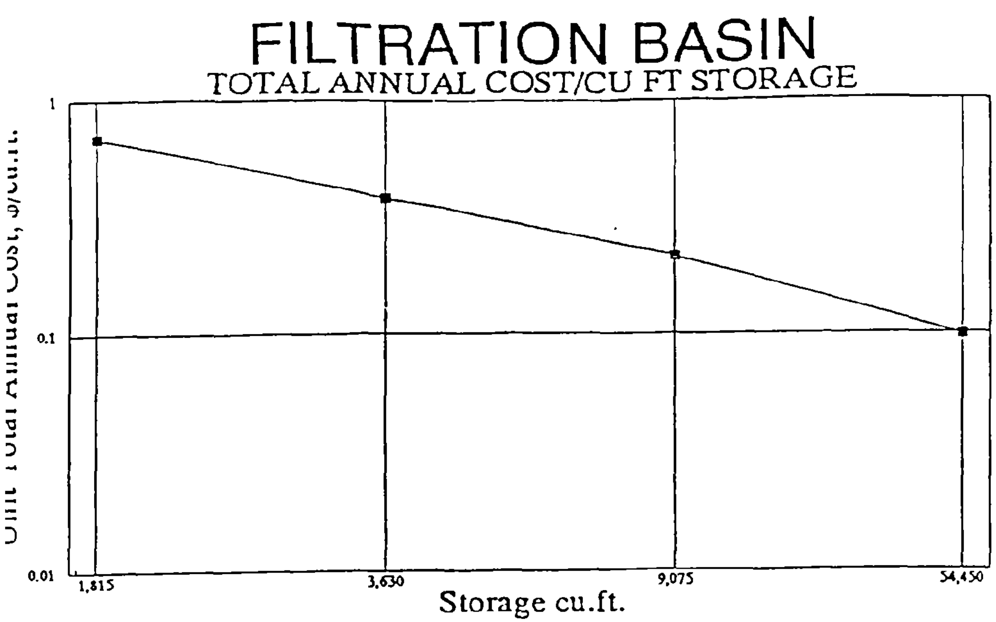
*there is a net decreased in operation and management cost for concrete pavements with life span of 20 years

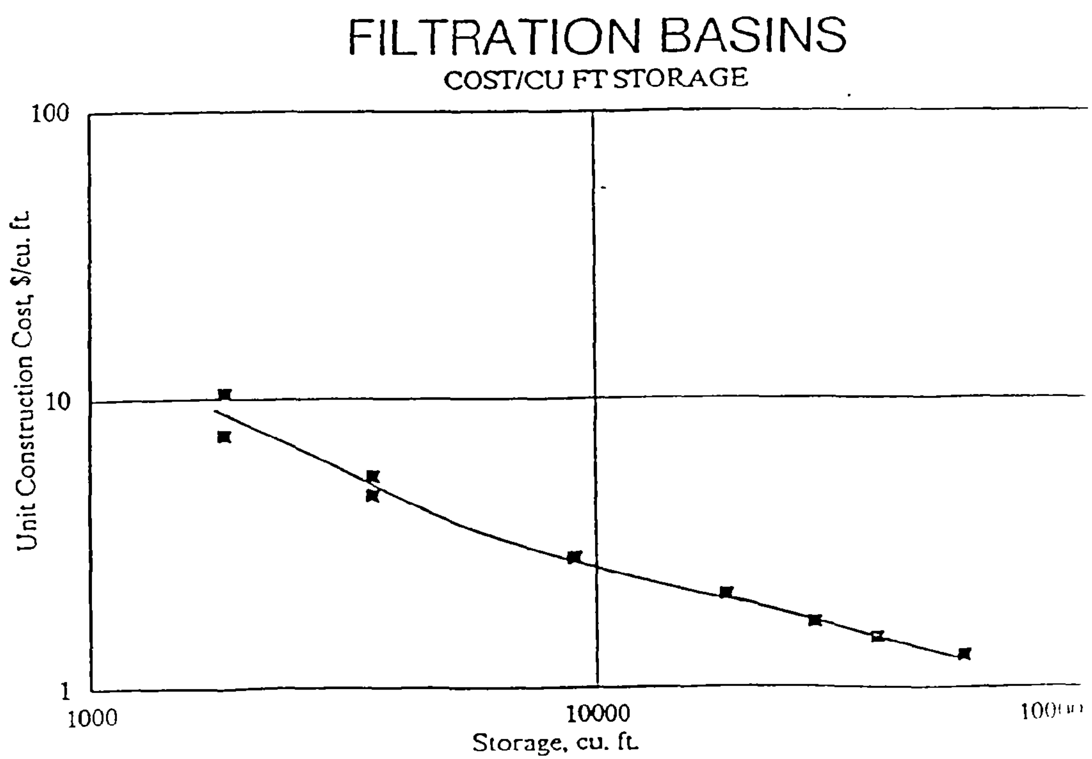
FILTRATION BASINS

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

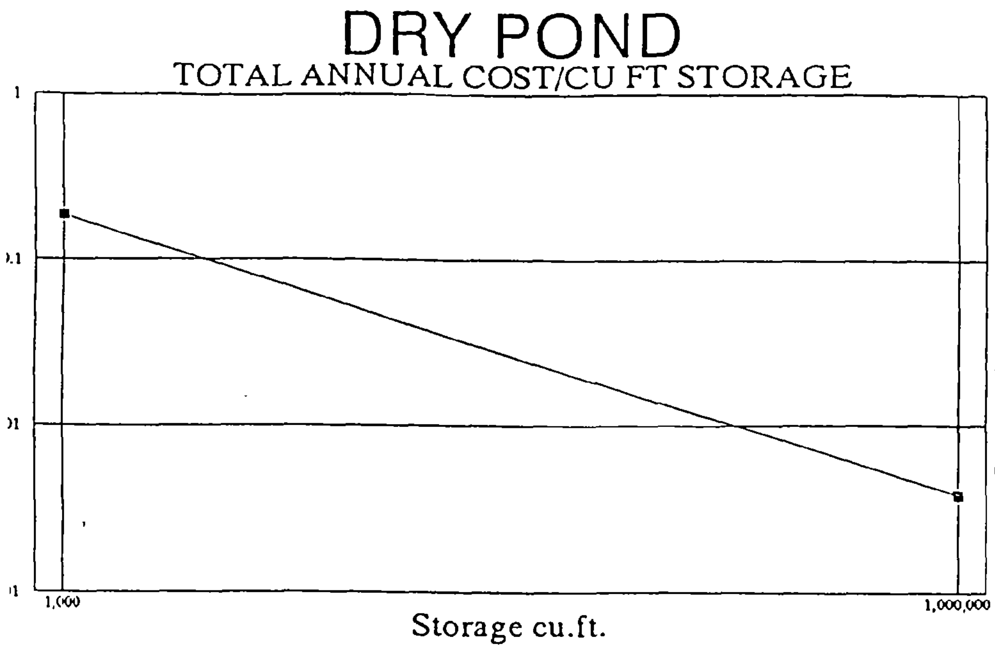
Storage Volume (cu. ft.)	Drainage Area (acres)	Total Cost (1988 $)	Cost/Cu. Ft. ($/cu. ft.)	Cost/Acre ($/ac.)
6,530	8	12,018	1.84	1448
13,940	36	11,985	0.86	337
15,250	11	7,673	0.50	731
16,120	18	5,031	0.31	287
25,260	16	9,412	0.37	592
28,310	12	11,847	0.42	982
37,900	227	7,899	0.21	35
48,790	43	12,269	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

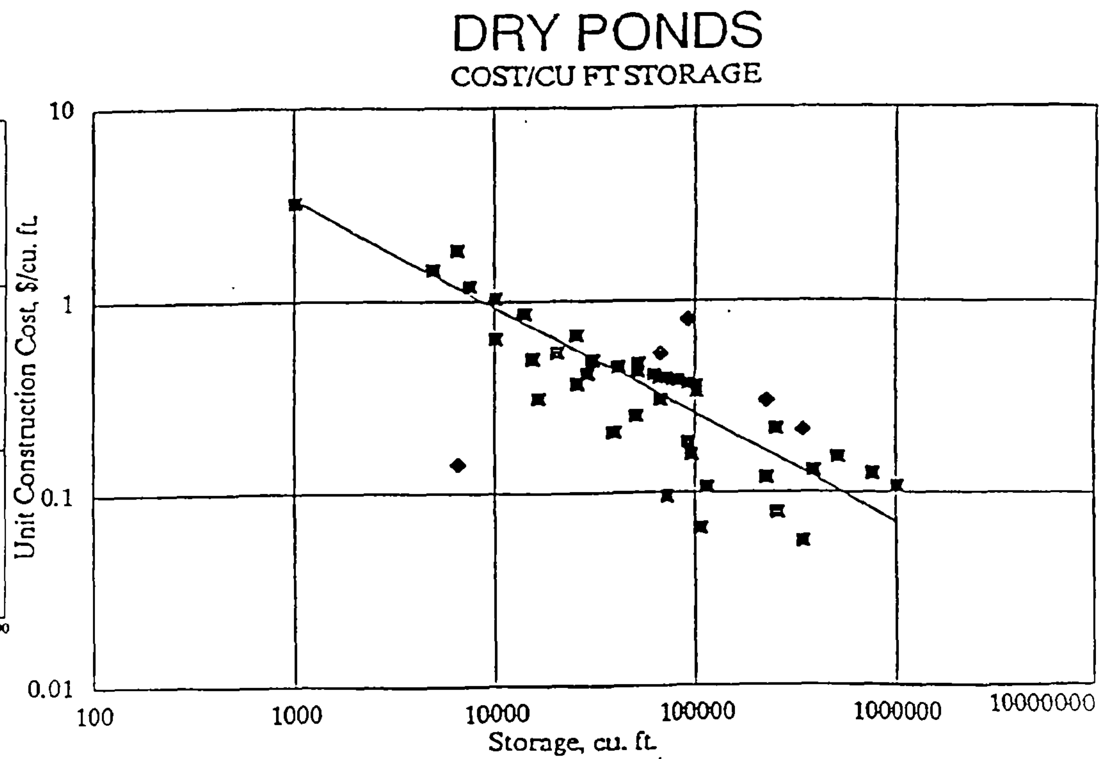
DRY PONDS – Washington, DC (based on WASHCOG NURP equation from regression analysis for approx. 30 dry ponds) EPA, 1983

$C=77.4*V^{0.51}$

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%

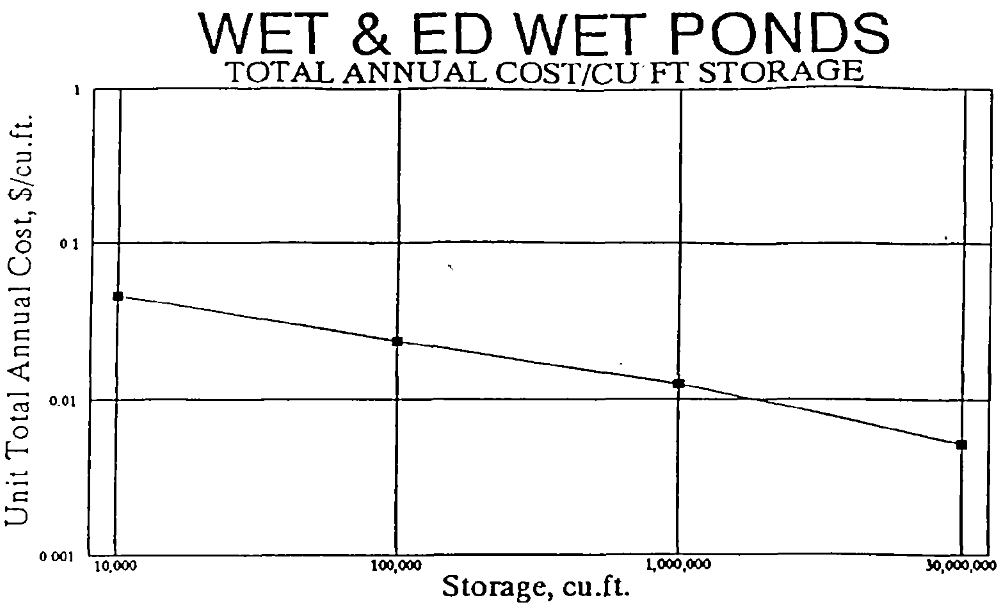
NA: Not Available

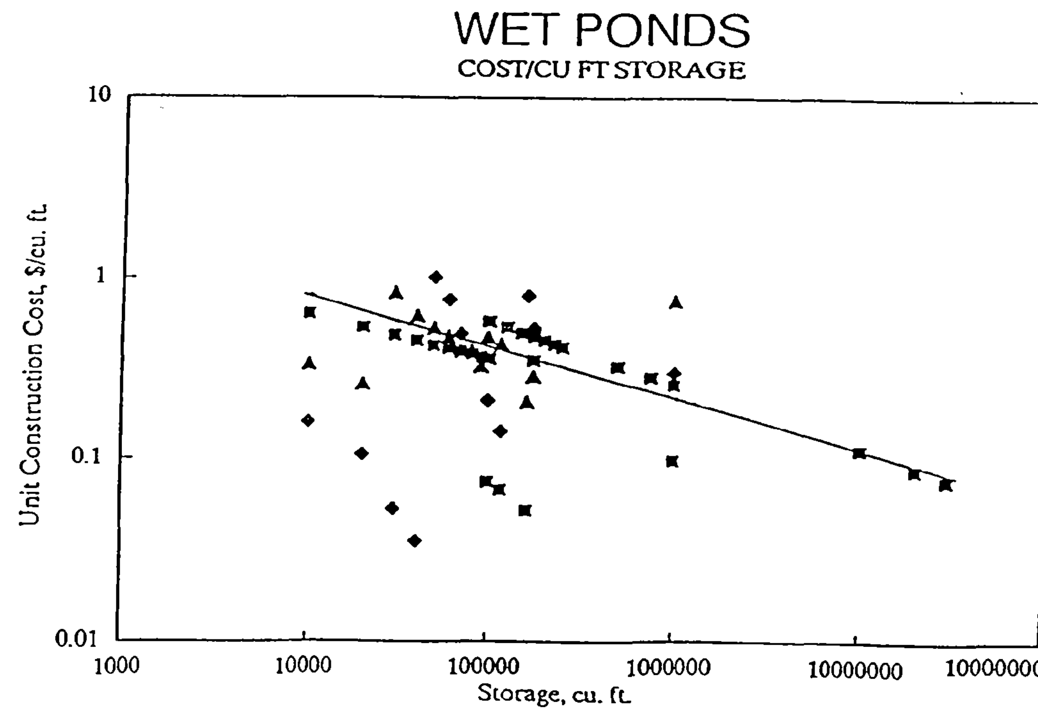
STREET CLEANING – OPERATION COST

includes: wages and salaries, indirect labor, benefits, overhead, fuel, maintenance/materials, equipment depreciation, and disposal

Location	Cost per Curb–Mile (1989 $'s)	Reference
EPA Region 4		
Winston–Salem, NC	$17.90	SWRPC, 1991
EPA Region 5		
Milwaukee 1976	$18.07	SWRPC, 1991
Milwaukee 1977	$17.53	SWRPC, 1991
Milwaukee 1978	$22.62	SWRPC, 1991
Milwaukee 1979	$20.61	SWRPC, 1991
Milwaukee 1980	$19.96	SWRPC, 1991
Milwaukee 1988	$25.05	SWRPC, 1991
Milwaukee 1988	$25.00	SWRPC, 1991
Champaigne, IL	$14.30–18.00	SWRPC, 1991
EPA Region 9		
San Francisco, CA	$12.90–19.40	SWRPC, 1991
San Jose, CA	$27.20	SWRPC, 1991

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





STREET CLEANING – CAPITAL COST

Sweeper Type	Capital Cost (1989 $'s)	Reference
Mechanical:		
Elgin Pelican	$65,000 – 75,000	SWRPC, 1991
FMC Vanguard 4000		SWRPC, 1991
Single broom	$89,225	
Double broom	$93,550	
Vacuum:		
Elgin Whirlwind	$120,000	SWRPC, 1991
VAC/ALL Model E–10		SWRPC, 1991
Single broom	$61,000	
Double boom	$73,467	
Regenerative Air:		
Elgin Crosswind	$110,000	SWRPC, 1991
FMC Vanguard 3000SP		SWRPC, 1991
Single broom	$73,165	
Double broom	$77,700	
TYMCO Model 600	$87,000	SWRPC, 1991

CAPACITIES AND COSTS OF SALT STORAGE BUILDINGS

Storage Building	Int. Dimensions (ft)				Usable Volume (yd3)	Capacity	Cost(a) ($)	Cost per ton est. salt capacity ($)
	w	l	hmax	h1				
Mass. Turnpike Wooden Arch	54	78	25	5	1620	1750	35,000	20
Mass. Turnpike Wooden Rigid Frame	56	77	25	6	1780	1925	50,000	26
California Dual Storage	50 19	79 50	16 16	7 7	1610 290	1740 310	133,000	65
Maine Concrete and Wood	28	40	12	4	260	285	6,200	22
North Carolina Crib with Sliding Roof	18	40	8	8	180	195	7,200	37
N.Y. Thruway Open Face, Concrete Block	38	27	20	14	310	330	22,000	66
Massachusetts DPW Braced Timber	36	80	18	8	1175	1270	21,000	17
Domar Dome	51 61 72 82 100 116 150	 Diameter		3 3 3 3 3 3 3	360 600 975 1430 2540 3920 8250	390 650 1060 1540 2750 4230 8970	11,000 14,500 18,000 24,000 30,000 42,000 100,000	28 22 17 16 11 10 11
Wheeler Creosoted Timber	28 28 48	39 83 120	16 16 16	14 14 14	430 1150 3020	465 1240 3260	16,000 20,000 36,500	34 16 11

(a) Paving typically not included

Deicing Management Practices

Deicing Materials Cost

Material	$/ton	Usage Ratio to that of Salt	Reference
Sand	$3		Foster, 1990
Salt (NaCl)	$25–50	1	Foster, 1990
NaCl:CaCl @ 4:1	$75		Land Management Project, 1989
Cargill 90	$150	1	Foster, 1990
GSL Qwiksalt	$150	1	Foster, 1990
Domtar TCI	$150	1	Foster, 1990
Urea	$225		Foster, 1990
Calcium Chloride	$250	0.8 – 1.2	Foster, 1990
GSL Freezgard	$370	unknown	Foster, 1990
Ethylene glycol	$625		Foster, 1990
CMA	$650	0.6 – 1.2	Foster, 1990

Control Application Cost

Method	Cost	Reference
Spread Rate Control on Trucks	$6,000/truck	Land Management Project, 1989

The Economic Cost of Road Salt – Results of Six Studies **
(Chevron Chemical Company, 1991)

Study Date	U.S. EPA 1976	TISA Study Salt Inst. 1976	Alaska DOT 1983	Ontario Ministry of Trans. 1985	NY Energy Develop. Authority 1987	Rensselaer Polytechnic Institute 1990
			$/ton of salt			
Salt Purchase Price	45	45	111	30	28	50
Vehicle Corrosion	454	145	1574	851	596	662
Highway & Bridge Corrosion	113	36	21	94	738	113
Parking Structure Corrosion				189		
Utilities Corrosion	2	0			170	
Water Supply Damage	34	2		1	114	
Environmental Damage	11	0		1		71
Total	660	230	1706	1166	1646	896
Amount of Road Salt Used	10,000,000	10,000,000	4,200	660,000	1,000,000	1,000,000
Total Cost in Study Area	$6,601,134,216	$2,295,652,174	$7,165,270*	$769,773,888	$1,646,168,401	$896,000,000

* Estimated cost if CMA, urea, & sand are used instead = $3,200,000 (Foster et al, 1990)

** All costs in 1990 dollars